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seismic safety element

Comprehensive
General Plan
City of Torrance

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UNIVERSITY OF CALIFORNIA

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The following revisions were made at the Planning Commission meeting of December 5, 1973.

page 1

The statements under Active Faulting should read:

1. Recent detailed investigations of the Palos Verdes fault zone indicate that it has not moved tectonically since late Lower Pleistocene, and is not considered geologically active. However, all branches may not have been located and geologic surveillance should continue as areas in and near the zone are developed.
2. No other active or potentially active faults (geologically speaking) are known in the City of Torrance.

and the following should be added:

3. The Palos Verdes fault zone has been determined to be seismically active with evidence of epicenters along the fault zone. An active program of monitoring the fault zone for seismic events and geological activity should be undertaken at locations recommended by professional geologists and seismologists.

page 97

The third paragraph under Continued Upgrading of Technical Data Base should read:

Water injection has been undertaken on a large scale in the Torrance oil field only recently (Appendix D) and it is too early to establish any firm relationship between the injection and micro-seismic activity. Therefore, a program to monitor the Palos Verdes fault zone as well as the water injection of the Torrance oil field should be jointly undertaken by the City of Torrance and the University of Southern California seismic research group. Seismic monitoring stations should be established in Torrance as part of a network to research the correlation between water injection and seismic activity.

and the following paragraph should be added:

As the data base used to establish the design factors has been approximated it would be best to review these parameters every five years and update the Seismic Safety Element as more exact information becomes available.

CITY OF TORRANCE
SEISMIC SAFETY ELEMENT

APRIL 1, 1973

[Envicom corporation]
Emerg. relief Earthquakes
Torrance
City planning 4

ENVICOM CORPORATION

00053

DRAFT



Physical, Ecological and Social Science Consultants

16255 Ventura Boulevard • Suite 615 • Encino, California 91316 • Telephone (213) 986-4203

April 1, 1973

City of Torrance
3031 Torrance Boulevard
Torrance, California 90503

Attention: Mr. Charles M. Shartle
Planning Director

Subject: City of Torrance Seismic Safety Element

Forwarded herewith is Envicom's report on the City of Torrance Seismic Safety Element. The report has been prepared with the intent to meet and comply with current California state guidelines governing preparation of this general plan element.

The City of Torrance Departments of Planning, Building and Safety and Administration have been involved in various study phases during preparation of the report. Special credit is extended to the Planning Department for their keen participation and contribution to report graphics design.

It has been our privilege to perform this study for the City of Torrance.

Sincerely,

A handwritten signature in dark ink, appearing to read "Donald O. Asquith".

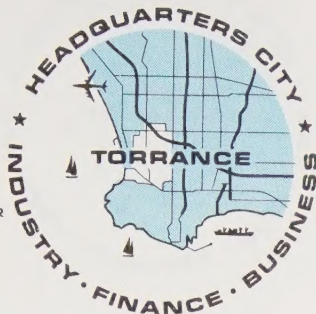
Donald O. Asquith
Engineering Geologist, EG 913

A handwritten signature in dark ink, appearing to read "Joseph G. Johns".

Joseph G. Johns
President

DOA,JGJ:ss

DEPARTMENT OF
BUILDING AND SAFETY
JOHN J. MCKINNON
BUILDING AND SAFETY DIRECTOR



CITY OF TORRANCE

3031 TORRANCE BOULEVARD, TORRANCE, CALIFORNIA
TELEPHONE (213) 328-5310 90503

March 19, 1973

Honorable Mayor Miller and
Members of City Council
City Hall
3031 Torrance Boulevard
Torrance, California

Subject: Proposed Policy Regarding the Seismic Safety Element of
the City of Torrance

Gentlemen:

Subject to approval by your honorable body, the Department of
Building and Safety proposes to:

- 1) Evaluate the existing buildings in the City of Torrance
regarding the seismic safety element, and...
- 2) Consider establishing a program for buildings to be con-
structed in the future.

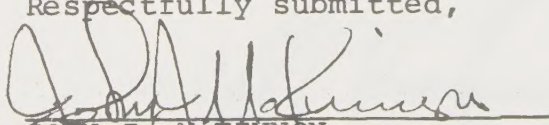
Evaluating existing buildings would involve identifying:

- a) buildings not under the control of the city and attempting
to obtain an evaluation of the seismic safety of the
building from the appropriate agency and,
- b) buildings under the control of the city which would be
classified as to age, use, and dangerous elements, such
as unreinforced parapets.

The program for future construction would include distribution for
design purposes, of the response spectra charts for the various
zones in the City.

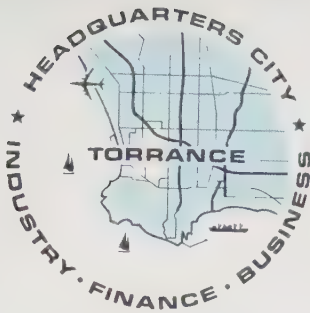
The charts and zones were established by the consultants that pre-
pared the Seismic Safety Element for the City.

Respectfully submitted,


JOHN J. MCKINNON
Building and Safety Director

JJM:bg

EDWARD J. FERRARO
CITY MANAGER



CITY OF TORRANCE

3031 TORRANCE BOULEVARD, TORRANCE, CALIFORNIA
TELEPHONE (213) 328-5310

90503

March 29, 1973

Honorable Mayor
and Members of the City Council
Council Chambers
Torrance, California

Gentlemen:

To comply with the requirements of the Seismic element of the general plan regarding a contingency plan in case of earthquake, the following documents are submitted as exhibits:

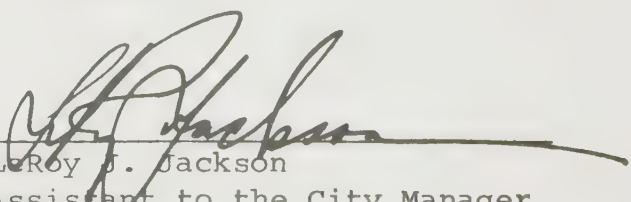
- (a) City of Torrance Emergency Operation Plan
- (b) City of Torrance Police Department Tactical Manual
- (c) City of Torrance Fire Department Manual Sec. C
Special Emergencies and Area G - Mutual Aid
Operations Plan

The City has on file mutual aid agreements for both Public Safety Response and Public Works Cooperation.

Any earthquake related evacuation plan in City would necessarily be committed to vehicular movement of the people. With the current restricted number of vehicular routes out of the City it is concluded that any mass evacuation would be inadvisable. No evacuation plan is therefore submitted.

Respectfully submitted,

EDWARD J. FERRARO
CITY MANAGER

By 
Leroy J. Jackson
Assistant to the City Manager

LJJ/rme

C

TABLE OF CONTENTS

CONCLUSIONS AND RECOMMENDATIONS	1
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TECHNICAL REPORT

I	INTRODUCTION	5
1.	Seismic Setting	5
2.	Philosophy of the Analysis	8
II	ACTIVE AND POTENTIALLY ACTIVE FAULTS	10
1.	General	10
2.	Palos Verdes Fault Zone	10
III	EARTHQUAKE SHAKING	14
A.	Historical Record	14
1.	Time Span of Useful Records	14
2.	Areal Distribution of Earthquakes Along the Newport-Inglewood Fault Zone	14
3.	Time Distribution of Earthquakes Along the Newport-Inglewood Fault Zone	16
4.	Discussion of Significant Earthquakes	19
a.	The Long Beach Earthquake	19
b.	The Signal Hill Earthquake	20
c.	The Gardena Earthquake	23
d.	The Torrance-Gardena Earthquake	23
5.	Summary of Historical Record	27
B.	Predictive Analysis	28
1.	Newport-Inglewood Fault Zone	28
a.	Recurrence of Intensity	28
b.	Recurrence of Magnitude	30
c.	Summary of Predictive Analysis for Newport-Inglewood Fault Zone	34
2.	San Andreas Fault Zone	34
C.	Risk	41
D.	Engineering Characteristics of Expected Earthquakes . .	43
1.	Scope and Intended Use	43
2.	General Characteristics and Maximum Acceleration for Firm Ground	43
a.	Data from Local Earthquakes	43
b.	Data From Other Sources	49

TABLE OF CONTENTS (cont)

c.	Zonation for Firm Ground	50
d.	General Characteristics of Expected Earthquakes for Each Zone	54
3.	Generalized Response Spectra for Firm Ground.	56
a.	Availability of Data.	56
b.	Generalized Response Spectra for Expected Earthquakes	58
4.	Variations Due to Local Conditions	66
a.	Near-Surface Soil Conditions	66
b.	Groundwater	69
c.	Modification of Spectra for Local Conditions	77
E.	Regional Effects of Expected Earthquakes.	90
1.	General Statement	90
2.	Earthquakes on the Newport-Inglewood Fault Zone	90
3.	Earthquake on the San Andreas Fault Zone	91
IV	SECONDARY HAZARDS.	92
1.	Landslide	92
2.	Settlement	92
3.	Liquifaction	93
4.	Tsunami	93
 <u>ROLE OF THE CITY OF TORRANCE IN IMPLEMENTING</u> <u>A PLAN OF SEISMIC SAFETY</u>		95

APPENDICES

A.	TERMINOLOGY AND CONCEPTS	A-1
B.	SIGNIFICANT LOCAL EARTHQUAKES POSSIBLY ORIGINATING ON THE NEWPORT-INGLEWOOD ZONE, MARCH 1933 THROUGH 1971.	B-1
C.	ACCELEROGRAPH RECORDS AND SPECTRA	C-1
D.	SUMMARY OF OPERATIONS, TORRANCE OIL FIELD	D-1
E.	REFERENCES	E-1

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Index map, selected faults, Los Angeles area	6
2	Location of earthquake epicenters, Newport-Inglewood fault zone	15
3	Occurrence of earthquakes and energy release by year.	18
4	Isoseismal map, Long Beach earthquake	21
5	Isoseismal map, Signal Hill earthquake	22
6	Isoseismal map, Gardena earthquake	24
7	Isoseismal map, Torrance-Gardena earthquake	25
8	Views of damaged buildings typical of Torrance-Gardena earthquake	26
9	Recurrence of intensity of shaking at Torrance	29
10	Recurrence of magnitude of earthquakes on Newport-Inglewood fault zone	32
11	Areas of contrasting seismic behavior, San Andreas fault zone	35
12	Magnitude vs displacement, San Andreas fault.	38
13	Recurrence vs magnitude, San Andreas fault	39
14	Maximum accelerations in rock for events M = 5.2 and 5.6	45
15	Maximum accelerations in rock for events M = 6.5 and 8.5	46
16	Accelerograms recorded at Long Beach station during Long Beach earthquake	48
17	Maximum accelerations in rock and "firm ground," City of Torrance	51
18	Seismic zones, City of Torrance.	53
19	Response spectra (0% of critical damping) for earthquake of magnitude 5.6 on Newport-Inglewood fault zone	60
20	Response spectra (5% of critical damping) for earthquake of magnitude 5.6 on Newport-Inglewood fault zone	61
21	Response spectra (0% of critical damping) for earthquake of magnitude 6.5 on Newport-Inglewood fault zone	62

LIST OF ILLUSTRATIONS (cont)

<u>Figure</u>		<u>Page</u>
22	Response spectra (5% of critical damping) for earthquake of magnitude 6.5 on Newport-Inglewood fault zone	63
23	Response spectra (0% and 5% of critical damping) for earthquake of magnitude 8.5 on San Andreas fault zone	65
24	Diagrammatic cross section illustrating near-surface amplification	67
25	Hydrograph from Torrance	70
26	Elevation of water table, 1903-1904	71
27	Elevation of water table, March, 1933	72
28	Elevation of water table, April, 1941	73
29	Elevation of water table, November, 1945	74
30	Elevation of water table, April, 1969	75
31	Depth to water table, 1969	76
32	Zone I response spectra	79
33	Zone II response spectra	80
34	Zone IIs response spectra	81
35	Zone III response spectra	82
36	Zone IIIs response spectra	83
37	Zone IIIIs response spectra	84
38	Zone IV response spectra	85
39	Zone IVb response spectra	86
40	Zone IVs response spectra	87
41	Zone IVts response spectra	88
42	Design spectra for 0% and 5% critical damping and ground motion spectra under consideration by City of Los Angeles	89

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Summary of known active and potentially active faults	7
2	Occurrence of earthquakes and energy release by years	17
3	Recurrence of intensity	30
4	Recurrence of magnitude, Newport-Inglewood fault zone	31
5	Recurrence of magnitude, single segment of Newport-Inglewood fault zone	33
6	Strain accumulation and fault slip, central and southern San Andreas fault.	37
7	Fault displacement and earthquake magnitude, lateral faults in California	40
8	Summary of accelerograph data from four local earthquakes, Los Angeles area, 1933-1941.	44
9	Seismic zones in the City of Torrance	52
10	General characteristics of expected earthquakes . . .	55
11	Amplification parameters	57
12	Amplification parameters for local variations	78

CONCLUSIONS AND RECOMMENDATIONS

Active Faulting

1. Recent detailed investigations of the Palos Verdes fault zone indicate that it has not moved tectonically since late Lower Pleistocene, and is not considered ~~active~~ ^{geologically}. However, all branches may not have been located and geologic surveillance should continue as areas in and near the zone are developed.
2. No other active or potentially active faults are known in the City of Torrance.

Earthquake Shaking

1. Analysis of recurrence of earthquakes on the Newport-Inglewood fault zone indicates the following events should be expected in the future on the zone at its nearest point to Torrance:

<u>Recurrence Interval</u>	<u>Magnitude (Richter)</u>
100-years	5.2
150-years	5.6
300-years	6.5

2. The recurrence interval can be considered a risk factor similar to that used in describing flood hazard.
3. Analysis of strain along the San Andreas fault zone indicates that the stress accumulation in the segment that last moved in 1857 is now sufficient to generate a "great" earthquake of a magnitude comparable to the 1906 San Francisco earthquake. This event can be expected at any time.

4. Earthquakes originating on the Newport-Inglewood fault zone will generate shaking of relatively high intensity and frequency but of short to moderate duration. The earthquake expected from the San Andreas fault, however, will be of moderate intensity, low frequency, and relatively long duration.
5. Engineering parameters for ten zones within Torrance are developed in the text and are shown in Table 10 and Figures 32 through 41. The zonation of the City is based on distance to the faults expected to be the sources of future earthquakes, and on the variation in rock and soil types within the City.

Secondary Hazards

1. The hazard from tsunamis, commonly called "tidal waves", is considered insignificant because of the abrupt topographic relief along the Torrance shoreline.
2. The hazard from earthquake generated landslides, settlements, or liquifaction is limited to the bluffs in the area south of Pacific Coast Highway. This hazard can be minimized by the utilization of engineering geology and soil engineering, backed-up by the enforcement of grading codes, in the design and grading of hillside developments in this area. The shaking parameters included in this report should be used with detailed data on conditions in evaluating stability in proposed developments.

Role of the City of Torrance in Implementing a Plan of Seismic Safety

1. The upgrading and enforcement of building codes for new construction should be aimed at preventing loss of life or serious injury. Increased levels of protection, over and above this basic level, should be the prerogative of the owner.

2. Increased levels of protection should be considered for critical structures such as hospitals, fire and police stations, and communications centers that would be critical in an emergency such as a damaging earthquake. By the same logic, lower levels of protection can be tolerated for structures, such as warehouses and automated manufacturing, that have a low level of occupancy.
3. Existing structures with a high risk (e. g. unreinforced masonry) should be identified and, if economically feasible, strengthened to meet acceptable levels. If strengthening is not feasible, other alternatives, such as reduction in the occupancy level or early redevelopment of the area, should be considered.
4. A disaster plan should be developed by the City that takes into account the effects of the expected earthquakes in the City, in surrounding communities, and on so called "lifelines" such as transportation and utility arteries. Two of the expected earthquakes will be major disasters in the Los Angeles area, and damage is expected to be greater in communities to the east and north. Consequently, the plan should be designed to insure the continued functioning of critical facilities within the City. Evacuation to a nearby community should not be considered a feasible solution. On the contrary, Torrance may be asked to accommodate earthquake victims from outside the City. The extent of this possibility should be determined on an area-wide basis by the City and/or County of Los Angeles.
5. The City should encourage the continued upgrading of the technical data base that is essential to the development and future upgrading of any plan of seismic safety. This could include the installation of accelerographs in major structures; detailed site

investigations for future high-rise construction; continued engineering geologic and soils engineering investigations in hillside developments, particularly along the Palos Verdes fault zone; and possibly the monitoring of micro-seismic events in the area of the oil field if future experience suggests that water injection may be inducing seismicity.

I. INTRODUCTION

1. Seismic Setting and Scope of Analysis

The City of Torrance is located in a seismically active area, and in close proximity to several of the many active and potentially active faults in Southern California (Figure 1). Damaging earthquakes have occurred in the City in the past, and can be expected in the future as the result of the recurrence of movement along these faults. This report is an analysis of the earthquakes that should be expected in the future, and the ground shaking that will be generated in the City. The resulting effect on particular structures is to be analyzed by personnel of the Torrance Department of Building and Safety utilizing the expected ground motion data.

For purposes of defining the problem, the principal active and potentially active faults in the region and their earthquake generating capability are listed in Table 1. The latter is expressed as the magnitude of the largest earthquake that can reasonably be expected, and also as the level of shaking (ground acceleration) that should result in Torrance. The approximate probabilities of occurrence that are listed should be considered as a relative scale, but with "likely" being greater than approximately 50% and "low" less than approximately 15%.

Three events in the table are of particular significance. The earthquake on the Newport-Inglewood fault will result in very high ground accelerations because the fault is so close to the City. The earthquake on the San Andreas fault is important because it has a high probability of occurrence, and because it will be one of California's "great earthquakes." The ground accelerations in Torrance will not be unusually high because the earthquake will be centered about 50 miles to the northeast, but strong shaking will probably last for the better

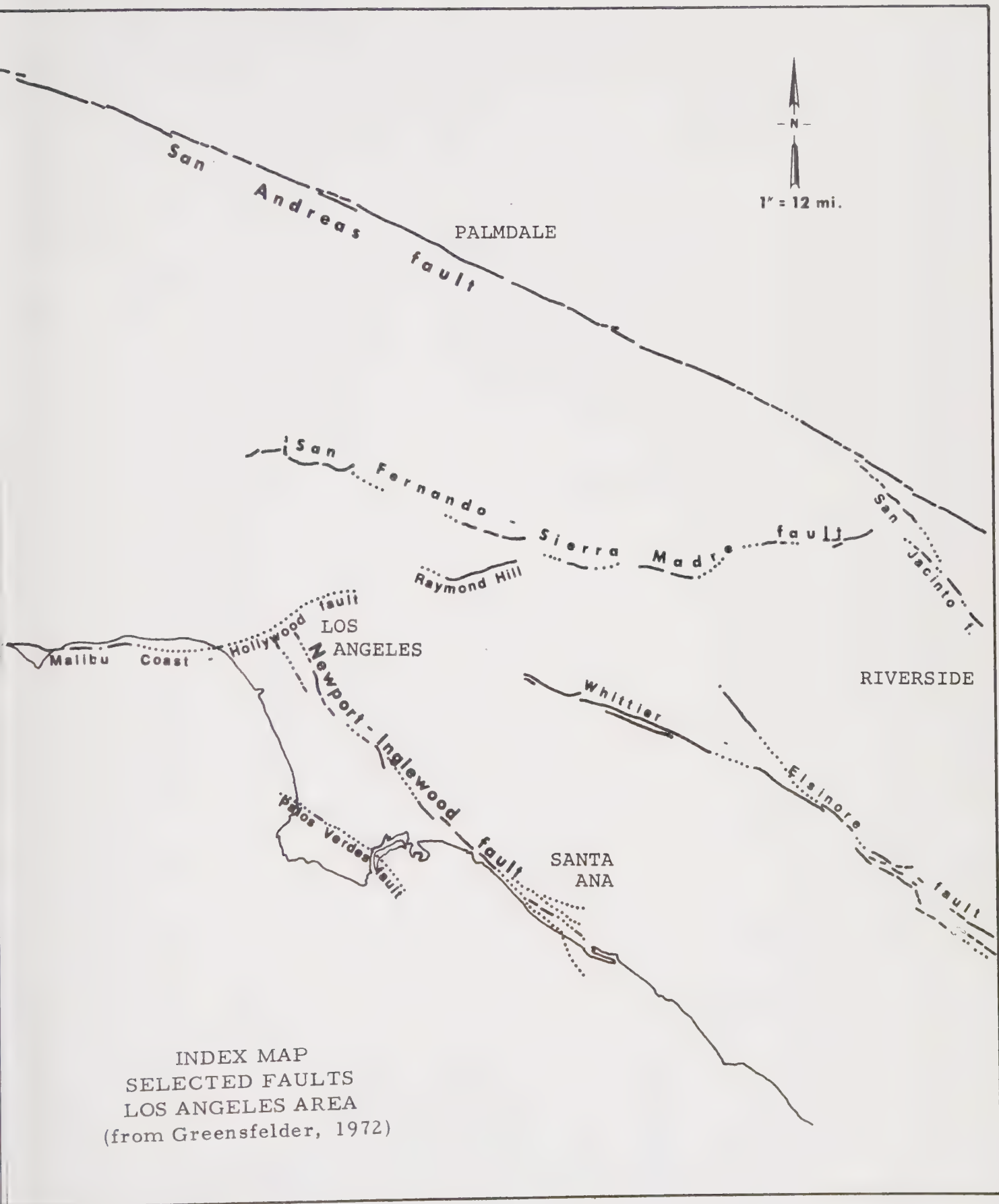


Figure 1.

TABLE 1
SUMMARY OF KNOWN ACTIVE AND POTENTIALLY ACTIVE FAULTS AND
THEIR EARTHQUAKE GENERATING CAPABILITY

Fault or Fault Zone	Distance from Torrance Miles	Expected Magnitude (Richter Scale)	Maximum Ground Acceleration at Torrance (Gravity)	Approximate Probability of Occurrence (100-Year Period)
<u>Active Faults:</u>				
Newport-Inglewood	2	6.0-6.5	0.25-0.65	Intermediate
Whittier-Elsinore	21	5.5-6.0	0.1 -0.15	Low
San Fernando-Sierra Madre	26-32	6.0-6.5	0.05-0.15	Intermediate
San Andreas	50	8.0-8.5	0.15-0.2	Likely
San Jacinto	70	6.0-7.0	0.05 or less	Likely
<u>Potentially Active Faults:</u>				
Palos Verdes	0	5.0-6.0	0.2 -0.6	Very low
Malibu Coast-Hollywood	17	5.5-6.5	0.1 -0.2	Low
Raymond Hill	23	5.0-6.0	0.05-0.1	Low

part of a minute. The third important item is the Palos Verdes fault. It has been generally considered as potentially active. Since residential structures have been built along its trace and others are proposed, a further consideration of the available evidence is necessary.

This report deals primarily with these three items. Section II considers the Palos Verdes fault zone, and the remainder of the report is primarily an analysis of expected ground shaking resulting from earthquakes on the Newport-Inglewood and San Andreas faults. Significant earthquakes can, and probably will occur on other faults. However, available evidence indicates that their effect in Torrance will be significantly less than those selected for detailed analysis.

2. Philosophy of the Analysis

The quantitative study of the strong shaking of earthquakes is a relatively young science. It was begun in California in the early 1930's, but has been limited by the necessity of having the right instruments in the right place when a significant earthquake does occur. Much information has been acquired over the last 40 years, but there are significant gaps and much remains to be learned.

With this relatively limited level of basic data, two different approaches to the development of a Seismic Safety Element are available. One can utilize broad generalizations to describe expected events; certainly the inadequacies of the data favor this approach. On the other hand, if the results are to be used by engineers in designing safer structures, then a commitment to mathematical form is necessary. To this end, the analysis is developed in this way, whenever possible, and presented in chart or graph form. Qualitative descriptions of the results are included for the lay reader, and a brief discussion of terminology and concepts is included as Appendix A.

The basic philosophy within which this analysis has been developed is that the intent of the Seismic Safety Element is to plan and prepare for the future based on what we know today rather than waiting until we know all that we would like to know.

II. ACTIVE AND POTENTIALLY ACTIVE FAULTS

1. General

Known active or potentially active faults that could be expected to be the site of ground rupture resulting from movement on the fault are limited to the Palos Verdes fault zone located along the southwest boundary of the City of Torrance (Figure 18). No other potentially active faults are known within the City (Calif. Div. of Mines & Geology, 1972a, and Greensfelder, 1972) and there are no trends of earthquake epicenters (Calif. Div. of Mines & Geology, 1972b) that would suggest a buried active fault within the City. Faults are known in deep wells in the Torrance oil field, but there is no evidence in groundwater conditions (Poland, 1959) that any of these cut Pleistocene or near surface rocks.

2. Palos Verdes Fault Zone

Information bearing on the recency of movement of the Palos Verdes fault zone and comments on the applicability of this information is summarized below by source:

1. The State geologic map (Jennings, 1962) shows the overall trend of the zone as a dotted line. This means that the fault zone is concealed by younger Pleistocene sediments. It also shows a short, arcuate fault near the base of the bluffs in the area west of the Walteria Park. This short fault segment appears to have been taken from mapping by Poland et al (1959) discussed below.
2. Mapping by the U.S. Geological Survey (Poland et al, 1959) shows no continuous fault or fault zone along the northeast flank of the Palos Verdes Hills, but does show the short segment noted above. The map (Plate 2, Southern Half) shows

the fault as cutting the terrace cover (Qpu) but not cutting small outcrops of San Pedro Formation (Qsp) present in the gullies and small canyons along the trace of the fault. Since the San Pedro Formation is older than the terrace cover, this relationship is improbable. Two explanations are possible: a) a drafting error; or b), the relationships shown are correct, and the feature mapped is a shallow break (e.g. landslide headscarp) rather than a fault. Discussion in the text is limited to (p 66): "...the Pleistocene rocks at the land surface are not ruptured (Wording, 1946, p 110, pls 1 and 21; Schultz, 1937, fig 4) except in the local area southeast of Redondo Beach (pl 2)." Because of the conflicting nature of the map relationships and the limited discussion in the text, this suggestion of post-terrace movement must be substantially downgraded with respect to the results of later, more detailed mapping.

3. Tract 30152. The report for the tentative tract by Geotechnical Consultants (12-28-64) states "...the uppermost units which were faulted were gravel beds of the San Pedro sand." The report of in-grading inspections by C. A. Yelverton (5-25-65) noted that the fault zone is 50-60 feet wide, but no mention is made of the youngest rocks faulted.
4. Tract 30301. The report by Geotechnical Consultants (12-29-64) states: "The Palos Verdes sand has been broken by the fault in the vicinity of Lots 36 and 38. In the other canyons to the east, the fault was observed to terminate at gravel beds of the San Pedro sand. Movement on this fault is, therefore, believed to have occurred during lower-upper Pleistocene time, or

about 10,000 years ago. No indications of recent movement on this fault was observed on the property."

5. Tract 26507. Investigations of the recency of movement in this tract have been much more extensive than in tracts developed earlier. Reports by Di Matteo (10-11-71 and 2-5-72) note the offset in the younger Pleistocene on the map of Poland (discussed above), correlate" with a fair degree of certainty" the "shear zone" mapped in the Tract with the Palos Verdes fault, and state that: "There is no factual basis for declaring the Palos Verdes fault to be active....".

Lindvall, Richter & Associates (4-10-72) in their review of the work done to that time observed that "...not sufficient is known to locate the exact trace of the Palos Verdes Fault, or to place the line of its most recent displacement." They also state: "If the terrace deposits can be shown to cross the fault zone undisturbed, the fault, historically speaking at least, is in a static condition."

Additional field work was conducted during August, 1972.

Two bulldozer pits were located and excavated under the supervision of Di Matteo, and the excavations were examined with Di Matteo by Roy Hoffman of Converse, Davis & Associates for the City of Torrance, and by C. Eric Lindvall of Lindvall, Richter & Associates. The report of this investigation by Di Matteo (9-5-72) states: "No evidence of fault disruption was found within the San Pedro Sand, which overlies the fault zone in a continuous blanket, simultaneously concealing and dating the fault. Field evidence from this latest excursion indicates that no fault disruptions have occurred since Lower

Pleistocene time....". Di Mateo translates this phrase as "in the last 285,000 years".

Conclusions based on the available data summarized above are as follows:

1. The Palos Verdes fault zone is a zone of faulting and intense folding 50-60 feet wide, or possibly more, in the Miocene Monterey Group.
2. The most recent tectonic movements cut the basal gravels and Lomita Marl Member of the San Pedro Formation (Lower Pleistocene), but do not cut the San Pedro sand.
3. The reference to the Palos Verdes (upper Pleistocene) being "broken" by the fault at two localities in Tract 30301 is unclear. However, it is not uncommon for faults to extend upward into overlying rocks as the result of the continuing differential compaction of previously faulted units. This type of movement would not be expected to recur.
4. The weight of evidence indicates the fault zone is not active and has not been since late Lower Pleistocene. However, geologic investigations of proposed construction sites along the trend of the zone should continue to be alert for any new evidence bearing on this problem.

III. EARTHQUAKE SHAKING

A. HISTORICAL RECORD

1. Time Span of Useful Records

Earthquakes that have had a significant effect on the City of Torrance have originated principally as the result of movement on segments of the Newport-Inglewood fault zone. Good records of earthquakes in this area have been kept since about 1933. A list of such earthquakes giving the date, general location, maximum intensity, intensity at Torrance if available, magnitude, and location of the epicenter for the period 1933-1971 is included as Appendix B. Records of earthquakes prior to 1933 are primarily qualitative descriptions of shaking and damage. They are of general interest, but are of little use in developing patterns that could be of value in predicting future events. (A detailed compilation of the pre-1933 data will soon be available to the public as a part of a study of the Newport-Inglewood zone by A. Barrows for the California Division of Mines & Geology.)

The analysis of the data contained in Appendix B is included in the next few sections of this report. The basic objective is to extract patterns useful in establishing what should be expected in the future.

2. Areal Distribution of Earthquakes (along the Newport-Inglewood Fault Zone)

The location of epicenters of earthquakes that have occurred along or near the Newport-Inglewood fault zone are shown on Figure 2. Epicenters shown are for the period 1933 to 1971. Records of the smaller earthquakes (generally less than magnitude 3.9) are not available for years prior to 1963, so the number of smaller quakes shown is considerably less than that which would be expected had they been recorded for the full 39-year period.

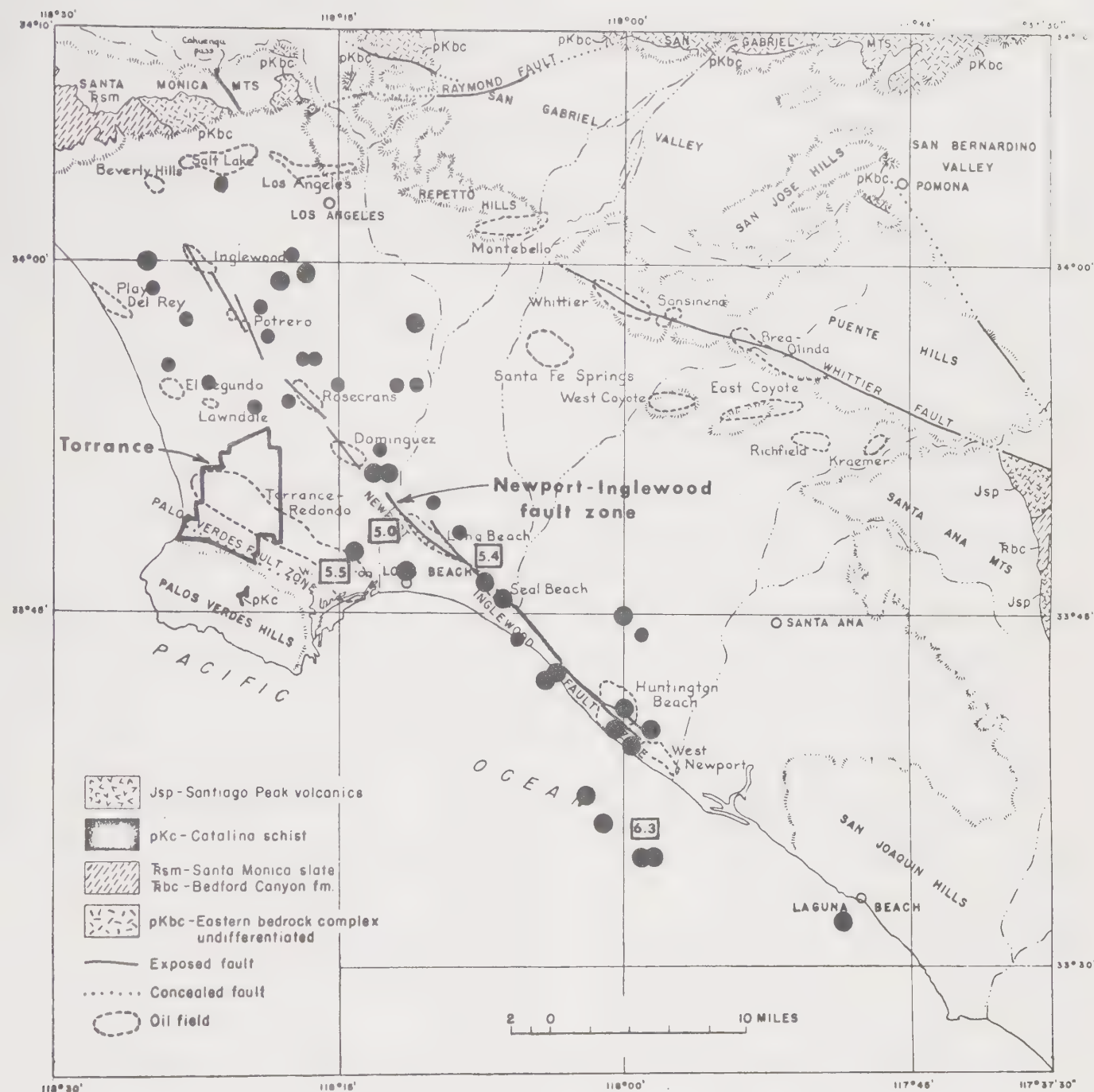


Figure 2. Location of earthquake epicenters along and near the Newport-Inglewood fault zone. Magnitude of earthquakes are as follows:

- 3.0 - 3.9
- 4.0 - 4.9
- 6.3 Magnitude as shown

Base map from Woodford et al (1954). Data from Appendix B.

The epicenters shown tend to concentrate along the fault zone, but many are located several miles from the surface trace of the zone. The location of the epicenters should not be considered precise as there are a number of assumptions involved in their location. Therefore, the assignment of a particular earthquake to a particular fault, or a particular segment of a fault zone, can be somewhat subjective. This problem will be discussed further in Section 4, Discussion of Significant Earthquakes.

The principal pattern that is apparent from Figure 2 is that the earthquakes along the northern portion of the fault, from approximately the Dominguez oil field to near Beverly Hills, have been of generally lower magnitude than those along the segment south of Dominguez. All of the larger earthquakes since 1933 ($M=5.0$ or greater) have occurred along the southern segment, while most of the smaller ones ($M=3.0-3.9$) are concentrated near the northern segment. For this reason, the further analysis of the data separates these two segments: a northern segment extending from the Beverly Hills to the Dominguez oil fields (see Figure 2); and a southern segment extending from the south end of the Dominguez oil field to Newport Beach.

3. Time Distribution of Earthquakes along the Newport-Inglewood Fault Zone

The occurrence of earthquakes and the seismic energy released by year are shown in Table 2, and the data are plotted in graph form in Figure 3. The energy, E , has been computed using the following formula and values from Bolt (1970):

$$\log E = aM + \log E_o$$

where:

M = magnitude of earthquake,

a = a constant with average value of 1.5, and

$E_o = 2.5 \times 10^{11}$ ergs.

TABLE 2
OCCURRENCE OF EARTHQUAKES AND ENERGY RELEASE BY YEARS

	Southern Segment			Northern Segment			Total		
Year	Number	Energy ($\times 10^{17}$ ergs)	Percent of Total Energy	Number	Energy ($\times 10^{17}$ ergs)	Percent of Total Energy	Number	Energy ($\times 10^{17}$ ergs)	Percent of Total Energy
1933	2	7500.0	92	1			2	7500.0	92
1934	2	5.0					2	5.0	
1935	1	14.0					1	14.0	
1937	1	2.5					1	2.5	
1938	2	17.0		1	2.5		3	19.5	
1939	1	14.0					1	14.0	
1940	4	10.0					4	10.0	
1941	2	530.0	6	1	1.3		3	531.13	6
1944				2	24.0		2	24.0	
		8092.5	99		27.8	0.2		8120.3	99.2
1961	5	35.0					5	35.0	
1963	1	0.08		2	0.48		3	0.56	
1964	1	0.16		1	0.08		2	0.24	
1965				1	0.08		1	0.08	
1966	1	0.45		1	1.3		2	1.75	
1967				1	0.06		1	0.06	
1968				1	0.08		1	0.08	
1969	1	7.1		2	0.22		3	7.32	
1970	1	0.08		5	1.4		6	6.48	
1971				2	0.53		2	0.53	
		42.87	0.5		37.03	0.3		52.10	0.8

Total, South Segment 99.5%

Total, North Segment 0.5%

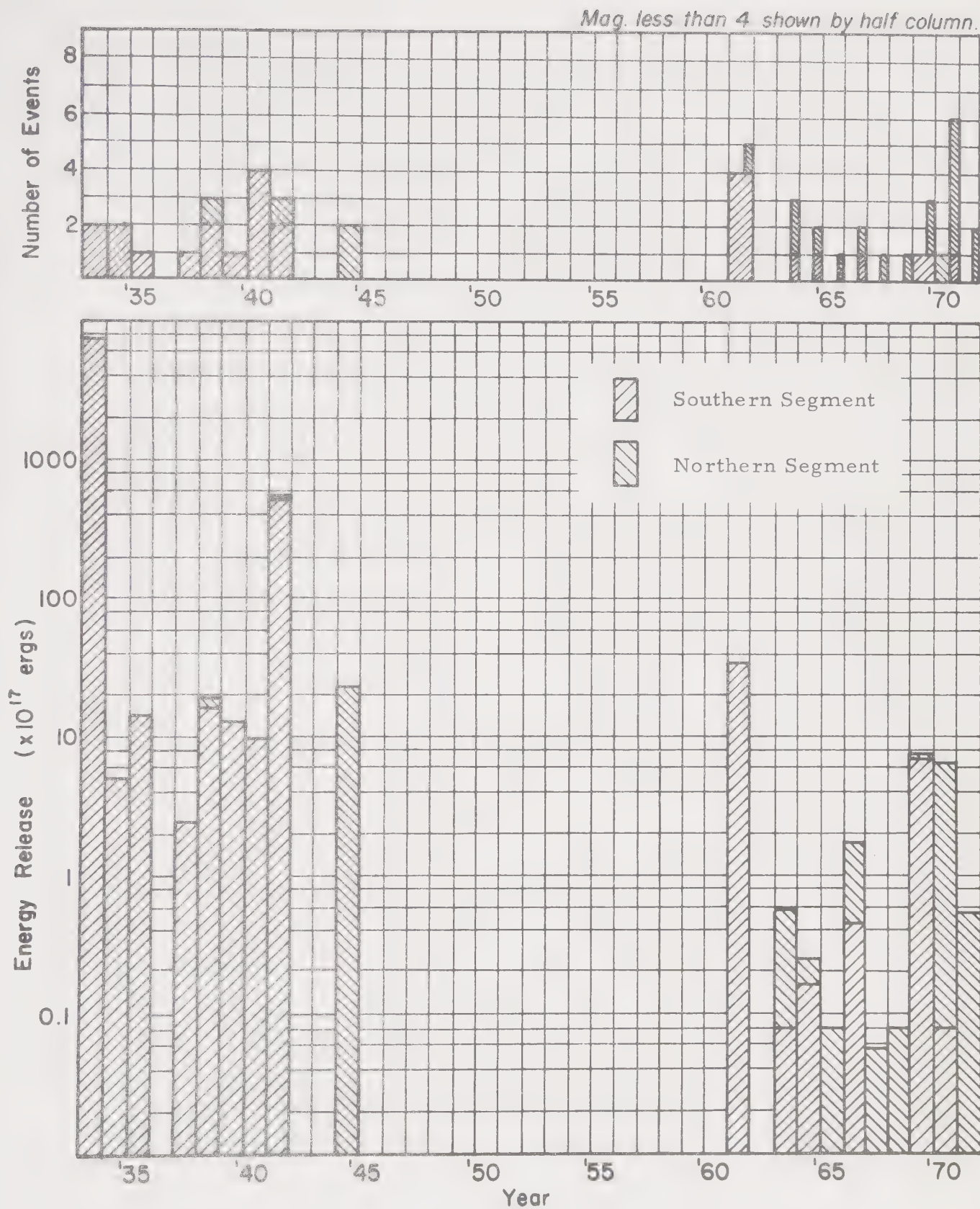


Figure 3. Occurrence of earthquakes and energy release by year on the Newport-Inglewood fault zone.

Several relationships are apparent from an examination of the table and the graphs:

1. Most of the larger earthquakes occurred in the interval prior to 1945. Of those that have occurred since then, 6 are in the range of $M=4.0-4.6$, and the remainder are less than 4.0 (shown by half column on the graph of the number of events by year).
2. Approximately 99% of the energy release occurred on the southern segment of the fault zone in the interval prior to 1942.
3. Four earthquakes released approximately 98% of the energy:

a. Long Beach, 1933	86.8%
b. Signal Hill, 1933	4.9%
c. Gardena, 1941	1.0%
d. Torrance-Gardena, 1941	<u>5.5%</u>
	98.2%

4. Discussion of Significant Earthquakes

a. The Long Beach Earthquake

The Long Beach earthquake of March 10, 1933 is the largest earthquake that has occurred on the Newport-Inglewood fault zone for which significant information is available. Damage is estimated to have been approximately 40 to 50 million dollars, and 90 deaths are attributed directly to the quake (Binder, 1952). Much of the damage was to masonry school buildings, and had the earthquake occurred while school was in session, the death toll would certainly have been much higher.

The areal distribution of the intensity of shaking is shown on the **Isoseismal Map** (Figure 4). This type of map shows the intensity of shaking on the Modified Mercalli Scale (see Appendix A) as deduced from the accounts of witnesses and the severity of damage to different types of construction.

The magnitude was 6.3, and the epicenter was located off Newport Beach approximately 4 miles southwest of the surface trace of the fault. Movement of the fault in the subsurface extended from near Newport to near Signal Hill (Bennioff, 1938). Rupture did not extend to the surface, and there was only a very small amount of damage to oil wells along the fault zone (Eaton, 1933).

The maximum intensity along the fault zone was generally VIII (Figure 4), but reached IX in areas of "bad ground" in Long Beach and Compton. The intensity at Torrance was VII. An important point to note is the asymmetry of the zones of equal intensity (isoseismals) near Torrance. Intensity VI was reported for Gardena near the northeast corner of Torrance, but the intensity VII zone extends westward through Torrance and for approximately 7 miles northwestward along the coast. On the other hand, the intensity drops-off rapidly in the area of the Palos Verdes Hills. These relationships recur on other isoseismal maps, and will be discussed further in the sections on zonation of the City.

b. The Signal Hill Earthquake

The Signal Hill earthquake of October 2, 1933 is sometimes referred to as an aftershock of the Long Beach earthquake. The magnitude was 5.4 and the epicenter was located near Long Beach (Figure 5). The isoseismal map is based on very limited information because of the problem of distinguishing the damage caused by this earthquake from

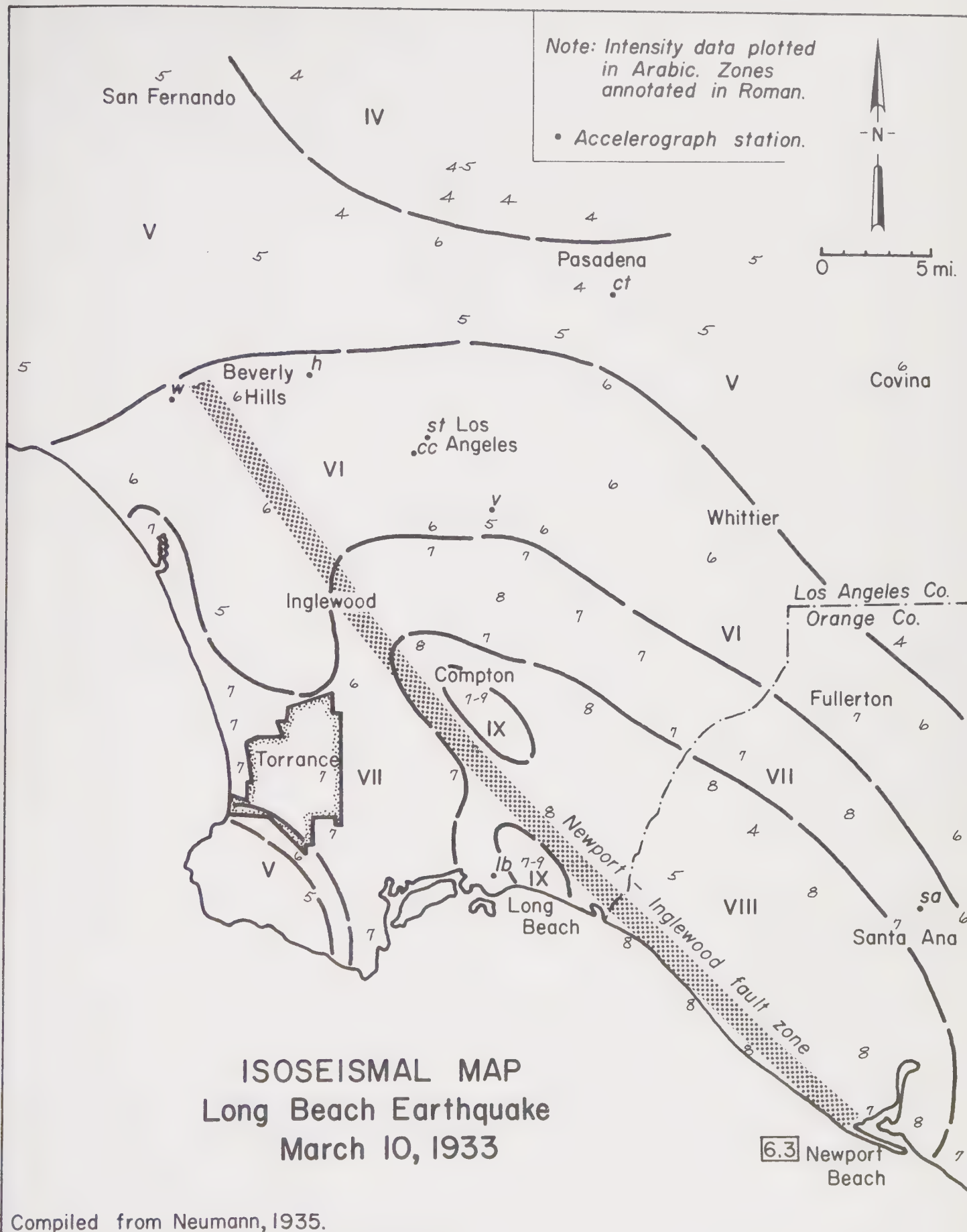


Figure 4.

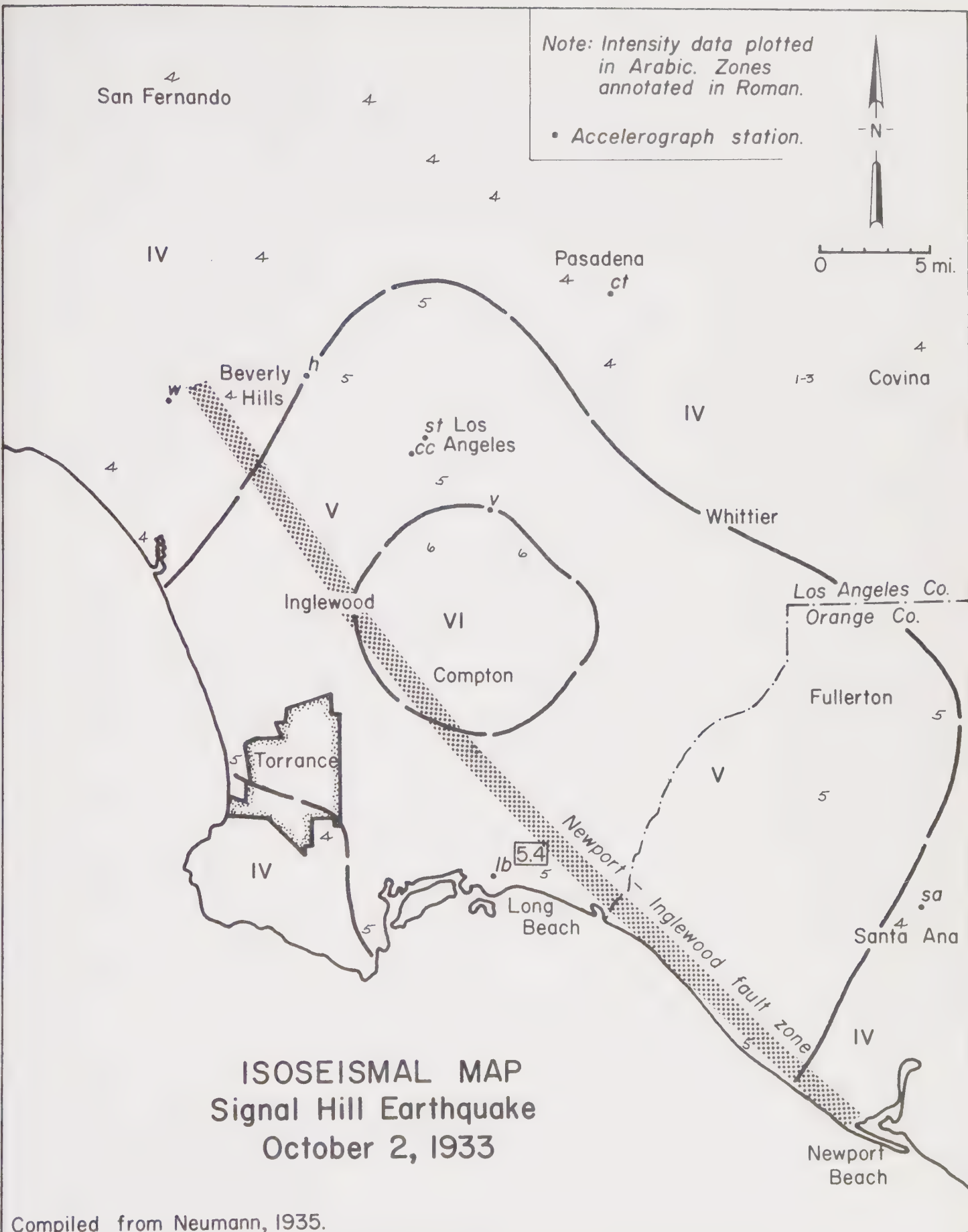


Figure 5.

that of the Long Beach earthquake only 7 months earlier. There is a suggestion of a problem in locating the epicenter, in that it and the zone of maximum intensity show a significant separation. However, the data are so limited, this relationship should be considered highly speculative.

c. The Gardena Earthquake

The Gardena earthquake of October 21, 1941 was the first of two important earthquakes in that year. The magnitude was 5.0, and the epicenter was located north of Long Beach near the south end of the zone of maximum intensity of VII (Figure 6). The intensity at Torrance was VI, and this zone, as in the Long Beach earthquake, extended northward along the coast to near what is now Marina del Rey.

d. The Torrance-Gardena Earthquake

The Torrance-Gardena earthquake of November 14, 1941 was the most damaging of the earthquakes in Torrance. The epicenter was located near Los Angeles harbor, but the zone of maximum intensity was centered further north at Torrance and Gardena (Figure 7). The assignment of this earthquake to a particular fault has been somewhat of a problem. The epicenter is located closer to the Palos Verdes fault zone than to the Newport-Inglewood, and on this basis, some have suggested that this earthquake may have originated on the Palos Verdes fault zone. The distribution of intensities, however, suggests that the earthquake was centered further north along the Newport-Inglewood fault zone.

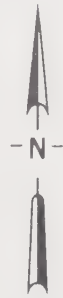
Damage in Torrance was moderate, and occurred primarily to the older, unreinforced masonry buildings. The collapse of unsupported masonry fire walls was particularly common. Numerous pictures of the damage were taken and are in the files of the Torrance Department of Building and Safety. Some typical views are shown on Figure 8.

San Fernando

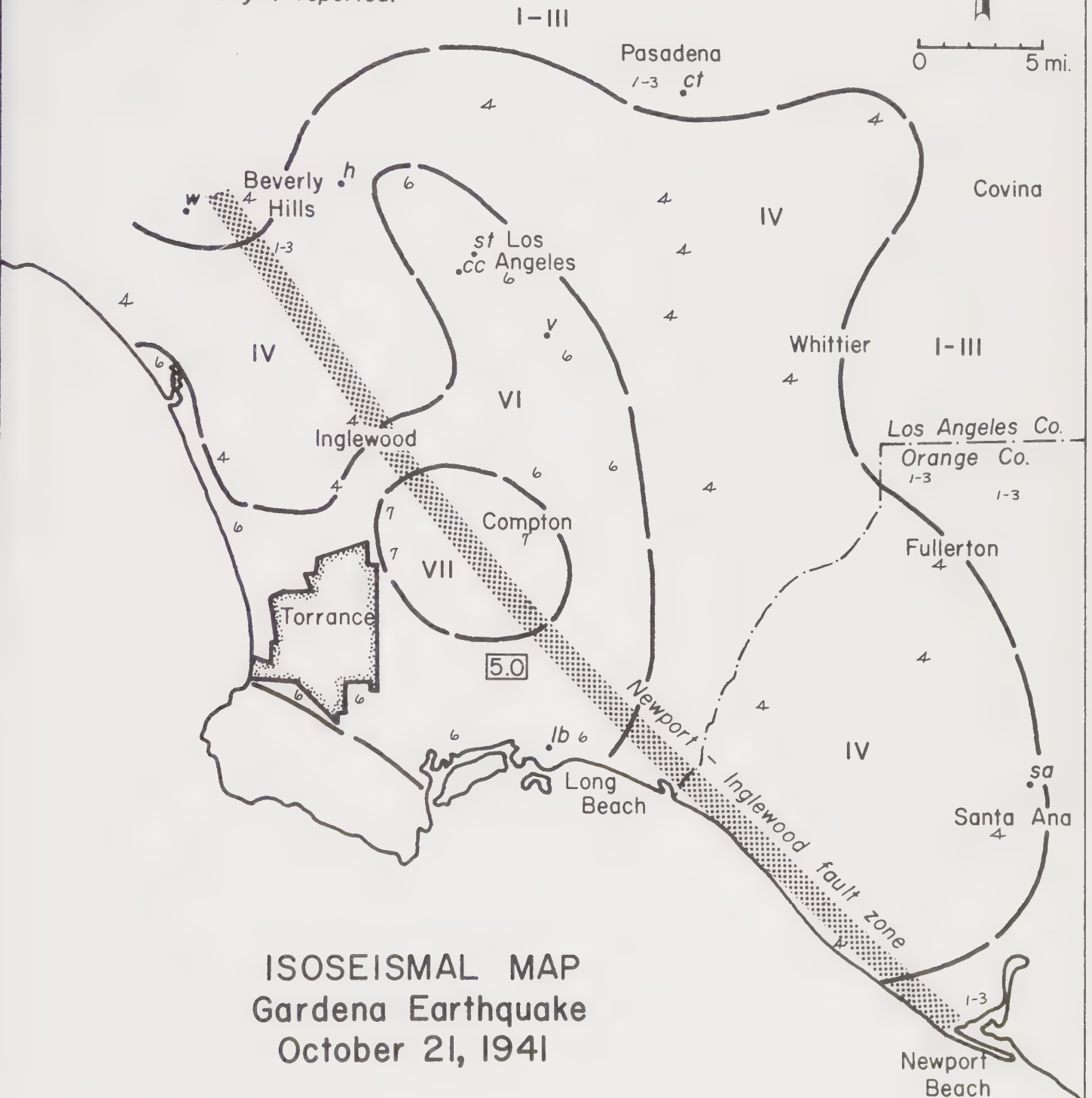
Note: Intensity data plotted
in Arabic. Zones
annotated in Roman.

• Accelerograph station.

Note: No intensity V reported.



0 5 mi.



ISOSEISMAL MAP
Gardena Earthquake
October 21, 1941

Compiled from Neumann, 1943.

Figure 6.

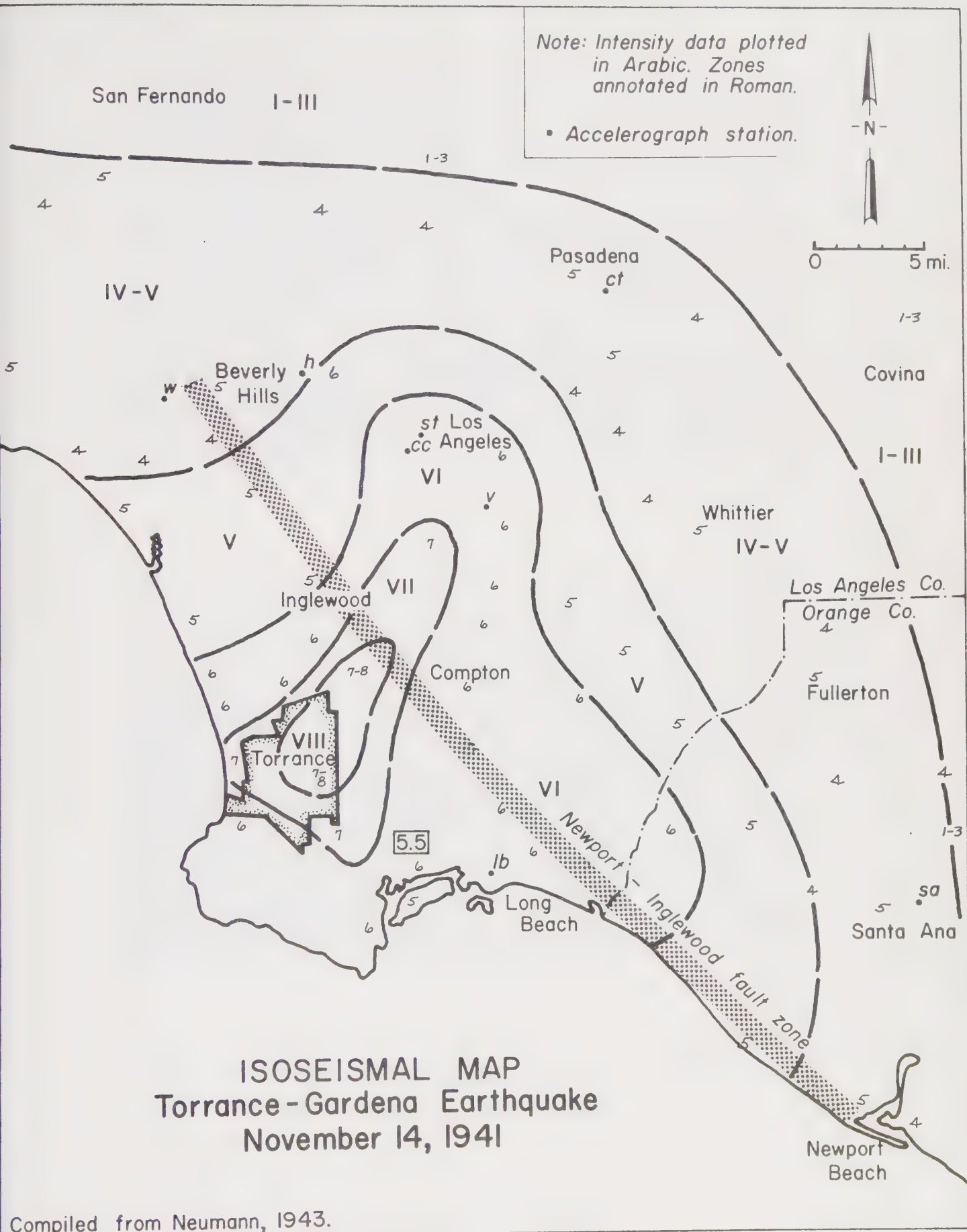


Figure 7.



Figure 8a. Collapse of fire walls was common in Torrance and Gardena. Location of bottom photo is 1509 Cabrillo Avenue.



Figure 8b. Collapsed fire wall above, and reconstruction of Torrance Herald building below.



Figure 8c. Collapsed roof of building on Sartori Avenue above, and collapsed 55,000 barrel oil tank below. Tank was about $\frac{2}{3}$ full at time of earthquake.

5. Summary of Historical Record

When considered as a whole, a pattern emerges from the recent (1933 to present) record of earthquakes on the Newport-Inglewood fault zone. The principal release of energy (87%) occurred in March 1933. The fault-break began near Newport Beach and propagated northwestward to near Signal Hill. Three earthquakes of intermediate magnitude, totaling approximately 11% of the energy release, have since occurred near the north end of the March, 1933 break. The last of these occurred in November, 1941, and the fault zone has been relatively quiet since that time. Small earthquakes (magnitude less than 5.0) have occurred since, but the energy released is insignificant (less than 1%) in comparison to that released during the larger earthquakes.

For each of the four earthquakes considered in detail, there is a consistent relationship between the epicenter and the center of damage. In each case, the epicenter is south of the center of damage, suggesting that the fault slippage is consistently originating on southwest end of the rupture zone and moving toward the northwest. This relationship, together with the time sequence discussed in the paragraph above, suggests a northwesterly-moving pattern of fault slip. The southern segment slipped in 1933, and adjustments at the boundary between the northern and southern segments have occurred since that time. That the northern segment is next to move is the most reasonable conclusion. How and when this will occur is not indicated by the record. It could happen as a series of earthquakes of intermediate magnitude (5.0-5.5), or as one larger quake similar to Long Beach.

B. PREDICTIVE ANALYSIS

1. Newport-Inglewood Fault Zone

a. Recurrence of Intensity

The recurrence of intensity is one of the most common methods of predicting the occurrence of shaking in the future. The basic assumption is that the recurrence of a particular intensity of shaking in the future will be similar to the recurrence of that intensity in the past. Studies by Algermissen (1969) indicate that for relatively large areas, the recurrence of intensity is proportional to the log (base 10) of the number of events in a fixed period of time. The recurrence rates on Figure 9 for the State, the San Francisco area, Bishop and Northeast California were taken from the California Urban Geology Master Plan prepared by Woodward-Lundgren & Associates in conjunction with the California Division of Mines and Geology. This method works well for relatively large areas, but must be applied with great care for smaller areas.

The recurrence of intensity at Torrance resulting from earthquakes during the period 1933-1971 on the Newport-Inglewood fault zone are given in Table 3. These values, corrected to the 100-year period, are plotted on Figure 9 with an "X". The interpreted recurrence at Torrance is based primarily on the values for intensity VII and VIII. The values for the lesser intensities are assumed to be too low because: 1) the data does not include intensities of earthquakes originating on other faults; and 2), intensities for the smaller earthquakes are not generally recorded (note Appendix B).

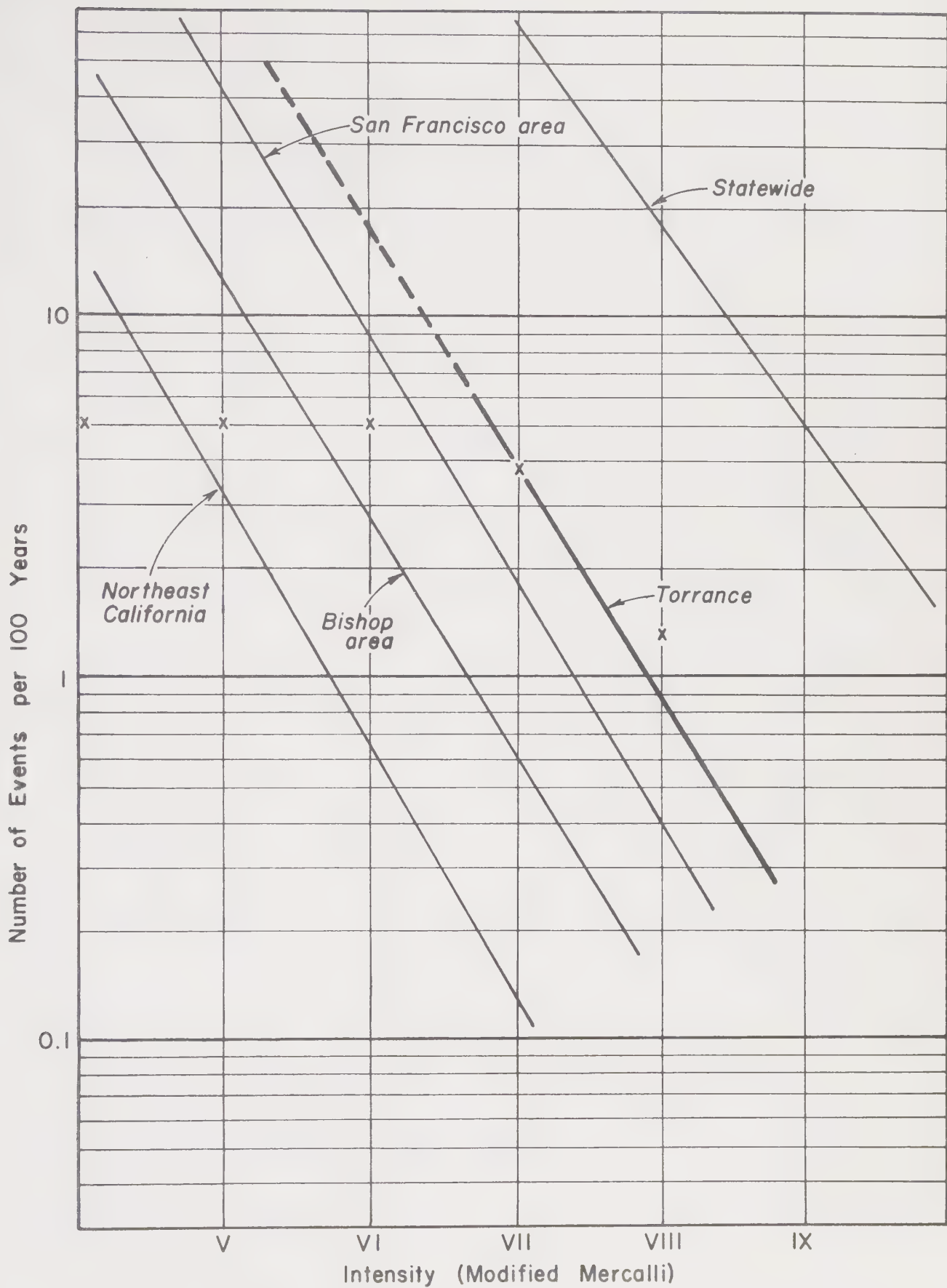


Figure 9. Recurrence of intensity of earthquake shaking at Torrance and some other areas in California.

TABLE 3
RECURRENCE OF INTENSITY

Intensity	Number of Events* (39-Year Period)	Number of Events (100-Year Period)
IV	2	5.1
V	2	5.1
VI	2	5.1
VII	1-1/2	3.8
VIII	1/2	1.3

b. Recurrence of Magnitude

A better method for areas like Torrance, where the seismic history is dominated by the events originating from one fault, is the recurrence of magnitude on that fault. In applying this method to predictive analysis, the assumptions are the same as for recurrence of intensity.

Data for the period 1933-1971 (Appendix B) is summarized in Table 4. These values are normalized to a 100-year period and show both as events per 100 years and as a recurrence interval for each range of magnitude. The data are plotted on Figure 10 as heavy dots, and a recurrence rate for the Newport-Inglewood fault zone is interpreted from this data. The alignment of the data points is good with the exception of the point for the magnitude 6.0-6.4. This point is the Long Beach earthquake, and the interpreted rate assumes that an earthquake of this magnitude would still have occurred only once had the sampling interval been a complete 100-year period. This method has also been used by Allen et al (1965) in establishing recurrence rates

*From Appendix B

TABLE 4
RECURRENCE OF MAGNITUDE
NEWPORT-INGLEWOOD FAULT ZONE

Magnitude Interval	Number of Events*	Years Recorded	Events per 100 Years	Recurrence Interval (Years)
3.0 - 3.4	15	9	166	0.6
3.5 - 3.9	6	9	66.7	1.5
4.0 - 4.4	15	39	38.5	2.6
4.5 - 4.9	5	39	12.8	7.8
5.0 - 5.4	2	39	5.13	19.5
5.5 - 5.9	1	39	2.57	39.0
6.0 - 6.4	1	39	2.57	39.0

for a number of areas in Southern California. Their rate for the Los Angeles Basin is included on Figure 10 for comparison, and to emphasize the increased seismicity, particularly for larger magnitudes, in the area of the Newport-Inglewood fault zone.

The discussion above applies to the entire fault zone from Newport Beach to Beverly Hills. The recurrence of damaging earthquakes at Torrance will depend not upon the rate for the entire fault zone, but upon the rate for the segment of the zone nearest Torrance. This rate can be determined approximately by applying relationships between earthquake magnitude and length of fault rupture as determined by Bonilla (1970). The theoretical lengths of rupture are listed in column 2 of Table 5. The theoretical number of segments for the four arbitrarily chosen magnitudes are listed in column 3. The recurrence in years for each of the four magnitudes is listed in the last column. These values,

*From Appendix B

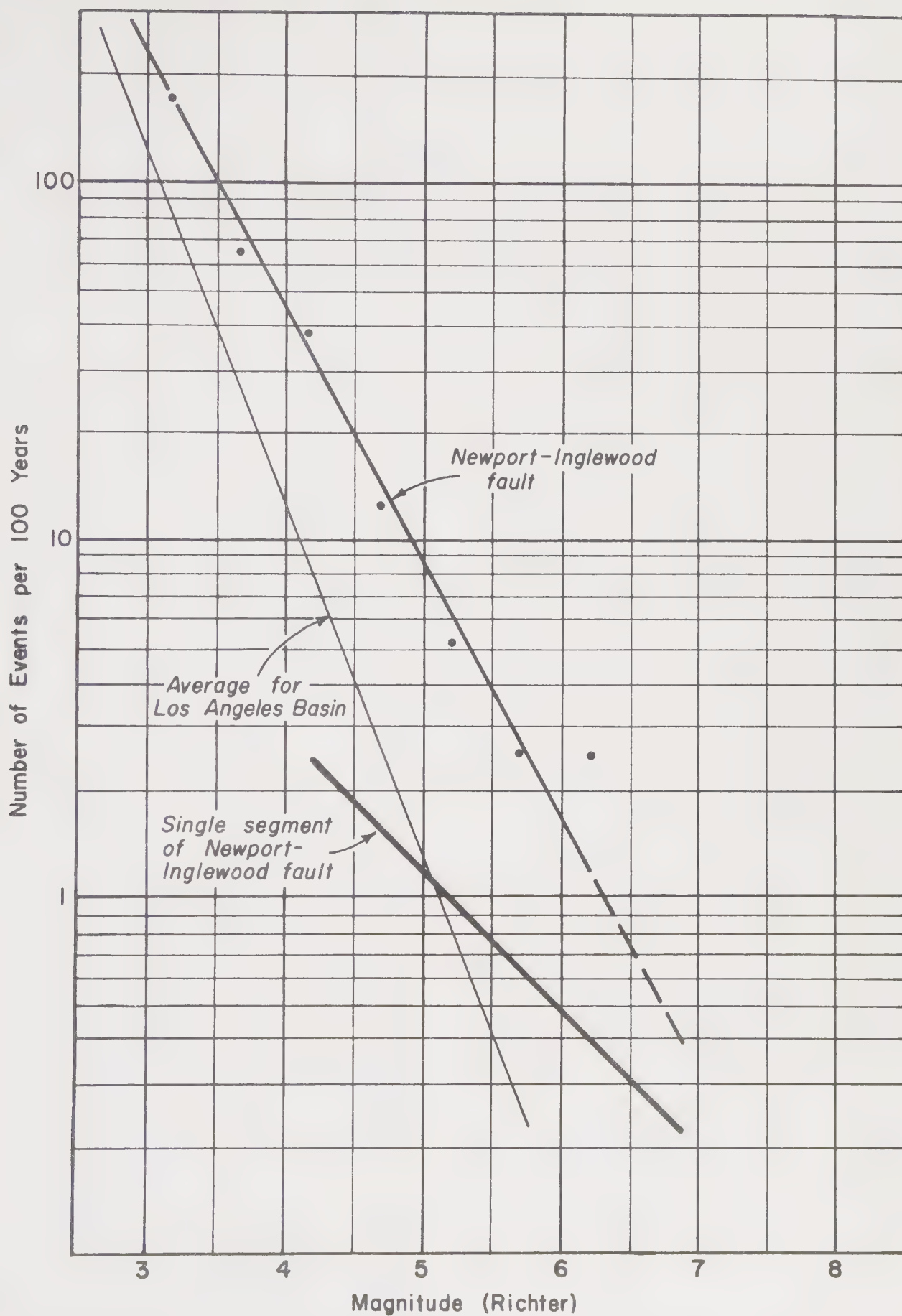


Figure 10. Recurrence of magnitude of earthquakes recorded on and near the Newport-Inglewood fault zone.

TABLE 5
RECURRENCE OF MAGNITUDE
SINGLE SEGMENT OF
NEWPORT-INGLEWOOD FAULT ZONE

Magnitude	Theoretical Length of Rupture (miles)	Theoretical Number of Segments (38 mile length)	Recurrence for Fault Zone from Figure 10 (years)	Recurrence for Single Segment (years)
5.0	5	7.1	11.8	84
5.5	7	5.4	26.2	142
6.0	12	3.2	58.8	188
6.5	18	2.1	143.0	300

converted to number of events per 100 years, are shown on Figure 10 as the curve annotated "Single segment of Newport-Inglewood fault." This curve represents the "discounting" of the curve for the entire fault for the relationship that smaller earthquakes result from the movement of shorter segments of the fault. The two curves converge at magnitude 7.7 which is the magnitude that would be expected should the entire 38-mile length of the zone move at the same time. Such an event can be considered the "maximum credible" earthquake for the Newport-Inglewood fault zone. Since the recurrence interval for an event of this magnitude is approximately 1000 years and the southern segment moved only 40 years ago, this potential event is not considered as having a sufficiently high probability of occurrence to be considered in this analysis.

c. Summary of Predictive Analysis for Newport-Inglewood Fault Zone

The analysis of recurrence of magnitude for the segment of the Newport-Inglewood fault zone nearest to the City of Torrance yields the following results:

<u>Recurrence Interval</u>	<u>Magnitude</u>
100 years	5.2
150 years	5.6
300 years	6.5

Analysis of recurrence of intensity yields results that are similar, but intensity is a generalization that is difficult to apply to specific problems. Therefore, the events listed above, and specified as a magnitude, are the events that will be considered in greater detail in later sections of this report.

2. San Andreas Fault Zone

The analysis of expected events from the San Andreas fault zone must be approached by a method that is very different from that used to analyze the Newport-Inglewood fault zone. This is because the movement of the segments of the fault zone are more complex, and because the data are different.

The San Andreas fault zone has been divided into several areas of contrasting behavior (Figure 11) by Allen (1968). The area of particular interest is the segment between San Bernardino and Parkfield that generated the Fort Tejon earthquake of 1857. This was one of the three "great earthquakes" of California's historic record, and this segment of the fault has not moved since. It is the closest part of the fault to Torrance, and it is generally considered as the segment capable of generating the largest earthquake.

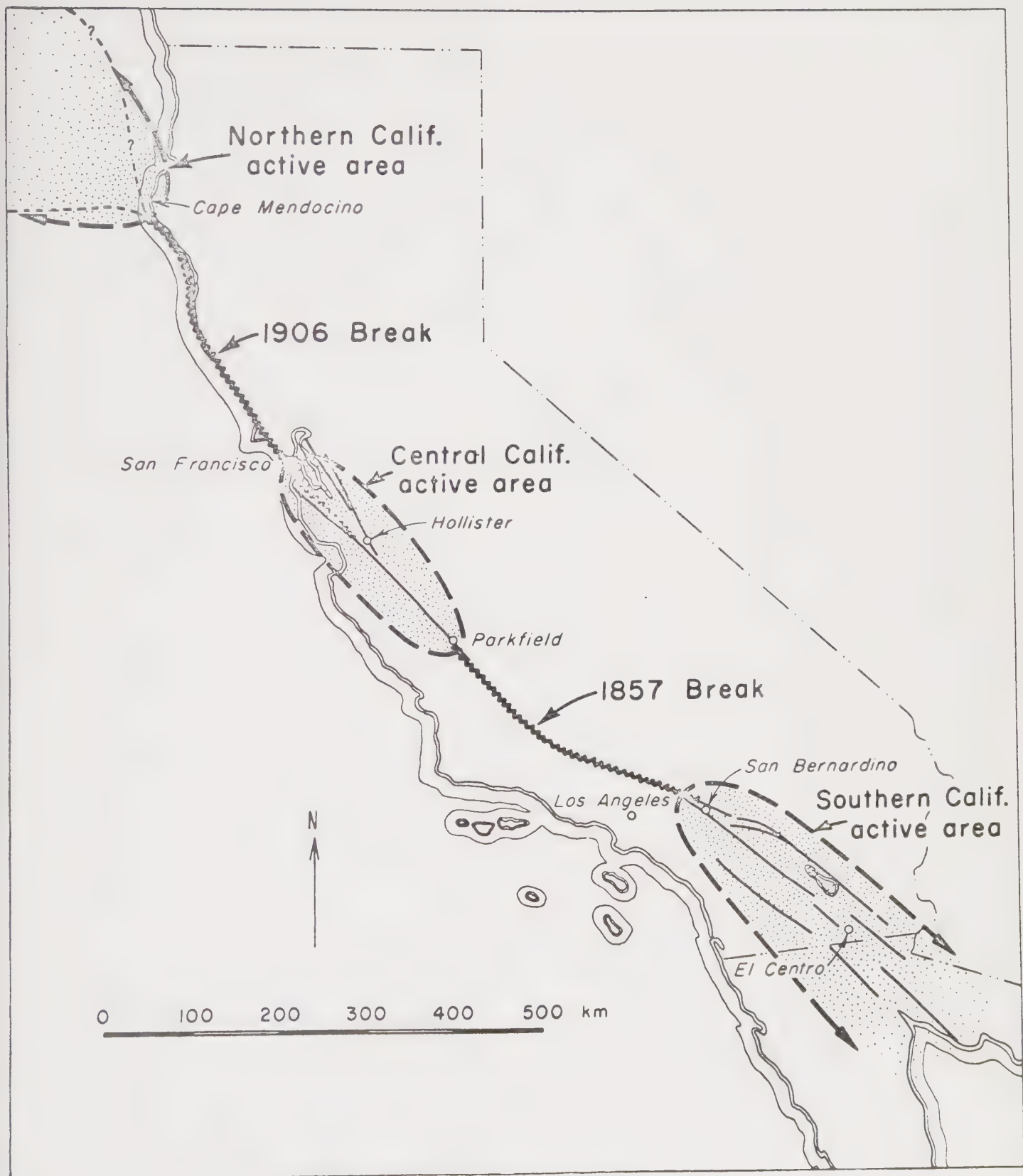


Figure 11. Areas of contrasting seismic behavior along the San Andreas fault zone in California.

(From Allen, 1968, page 72)

The segments of the fault to the northwest and southeast of the 1857 break are "active areas" that experience earthquakes of medium to small magnitude on a fairly regular basis. The 1857 break, however, is not moving, but is storing energy. The approximate rate of this storage can be deduced from the movements at either end. Pertinent data, summarized in Table 6, indicate that movement to the northwest is occurring at a rate of 5-6 cm/yr while that to the southwest is approximately 8.5 cm/yr. Current theory suggests that the differential between the two rates is being taken up in the Transverse Ranges near the south end of the segment, and that a rate of approximately 5-6 cm/yr is applicable to most of the segment of the 1857 break. This rate is compatible with other considerations (Brune et al, 1969) relating to movement on the fault.

The magnitude of the earthquake generated by slip on a fault is approximately proportional to the log (base 10) of the movement (surface displacement) that occurs. Data on displacement and magnitude compiled by Bonilla (1970) for the San Andreas and faults of similar movement are listed in Table 7 and are plotted on Figure 12. The fitting of a straight-line curve to the data is somewhat arbitrary, and in this process the values for the San Andreas itself are given more weight.

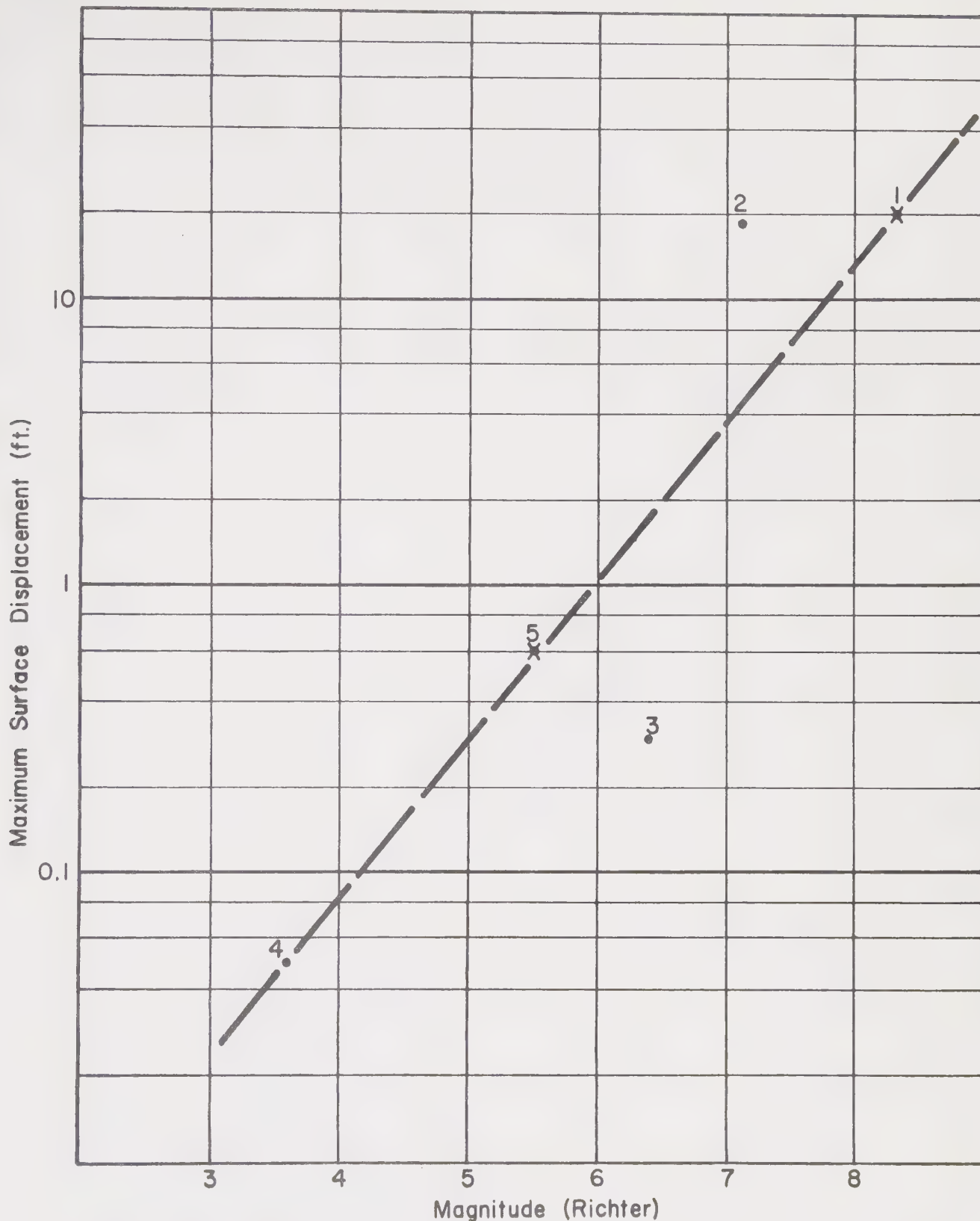
Magnitude and displacement (Figure 12) can be combined with a rate of displacement to give recurrence intervals for various magnitudes. Figure 13 shows this relationship for four rates of displacement. The most important consideration is that 115 years have past since this segment last moved. Regardless of the rate of displacement assumed, there is probably enough energy stored in this segment of the San Andreas fault to generate a major earthquake at any time. If a 6 cm/yr rate is valid, the energy stored already is sufficient to generate an earthquake

TABLE 6
STRAIN ACCUMULATION AND FAULT SLIP
CENTRAL AND SOUTHERN SAN ANDREAS FAULT

(From Greensfelder, 1972)

Area and Triangulation Net	Strain Accumulation and Fault Slip
1. <u>Central California Active Area:</u>	
a. San Francisco Bay Area, 1906 - 1969	5 - 6 cm/yr displacement between Mt. Diablo and San Francisco Penninsula; both strain and fault slip.
b. Salinas River, 1944 - 1963	3 cm/yr slip on San Andreas fault.
2. <u>Area of 1857 Break:</u>	
a. San Luis Obispo to Avenal, 1932 - 1951	1.5 cm/yr slip and strain.
b. Gorman, 1935 - 1956; Palmdale, 1938 - 1958; Cajon Pass, 1949 - 1963; Newport Beach to Riverside, 1929 - 1953	No significant movement detected.
3. <u>Southern California Active Area:</u>	
a. Imperial Valley, 1941 - 1967	8.5 cm/yr regional displacement.

See Figure 11 for location of areas.

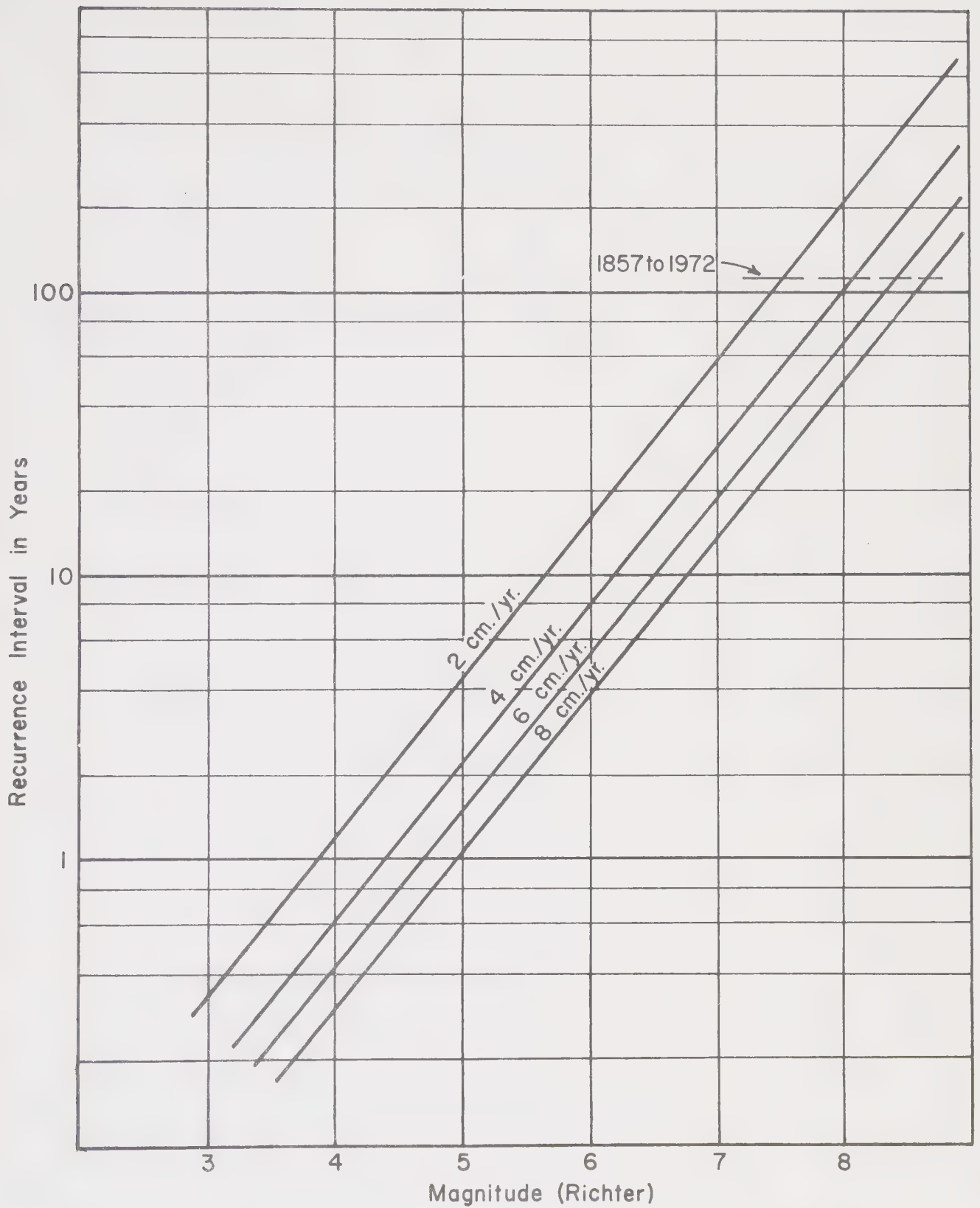


after Bonilla, 1970

x San Andreas fault
• other lateral faults

MAGNITUDE vs. DISPLACEMENT San Andreas fault

Figure 12.



RECURRENCE vs. MAGNITUDE

San Andreas fault

Figure 13.

TABLE 7
FAULT DISPLACEMENT AND EARTHQUAKE MAGNITUDE
LATERAL FAULTS IN CALIFORNIA

Fault	Year	Fault Displacement (feet)	Earthquake Magnitude (Richter)
1. San Andreas	1906	20	8.3
2. Imperial	1940	19	7.1
3. Mannix	1947	0.25	6.4
4. Imperial	1966	0.05	3.6
5. San Andreas	1966	0.6	5.5

of a magnitude of approximately 8.3. This is the estimated magnitude of the great San Francisco earthquake of 1906.

The reasoning developed in the paragraphs above is not new to most geologists, seismologists and earthquake engineers. It is the reason one hears from time-to-time about the prediction of a "great earthquake" on the San Andreas fault near Los Angeles. From a scientific standpoint such an earthquake must be considered as imminent. The question is not "if"; it is "when", and the longer it waits, the larger it will probably be.

For purposes of further analysis in later sections of this report, the magnitude of the expected earthquake is taken at 8.5. No specific recurrence interval is required for risk evaluation as the event appears certain to occur sometime in the next 100-year period.

C. RISK

The predictive analysis of events to be expected from the Newport-Inglewood fault zone has defined these events in terms of a magnitude and a recurrence interval. The level of risk associated with each event is indicated by the recurrence interval in much the same manner as the risk from other natural hazards such as flooding are defined by a recurrence interval. For example, it is common practice to design flood-prevention works to accommodate the flows from a 100-year storm. Where a higher level of protection is desired, as for example along the Santa Ana River in Orange County, the design levels are increased to accommodate the flows from storms occurring at roughly 300-500 year intervals.

The risk of earthquake can be considered in a similar manner. Design for the 100-year event is considered minimum; where a higher level of protection is desired, such as for hospitals, design levels should be increased to protect against earthquakes with longer recurrence intervals. The following levels are recommended for earthquakes expected from the Newport-Inglewood fault zone:

<u>Use</u>	<u>Recurrence Interval</u>	<u>Expected Magnitude</u>
<u>Limited occupancy</u> (warehouses, automated manufacturing facilities, etc.)	100 years	5.2
<u>Normal occupancy</u> (residences, normally occupied factories, etc.)	150 years	5.6
<u>Critical facilities</u> (hospitals, fire and police stations, schools, critical utilities, etc.)	300 years	6.5

The risk of earthquake from the San Andreas fault is a special case. As discussed in the previous section, a major or "great earthquake" is considered imminent. As a result, all structures except possibly limited occupancy should be designed for an earthquake of magnitude 8.5 on the San Andreas fault.

D. ENGINEERING CHARACTERISTICS OF EXPECTED EARTHQUAKES

1. Scope and Intended Use

The analysis of the engineering characteristics of expected events is divided into three sections: 1) general characteristics and maximum acceleration on firm ground; 2) generalized response spectra for firm ground; and 3) variations due to local conditions. The acceleration data are intended for use with one- and two-story residential and some commercial and industrial construction. The generalized response spectra are intended for use with medium-rise construction up to approximately 8 to 10 stories and as a first approximation for high-rise structures.

Higher structures, particularly if of flexible design, are more responsive to minor variations in site conditions than are lower and stiffer structures. The data developed herein could be used as a first approximation for a preliminary design of the higher structures, but individual site analyses should be conducted prior to the development of final design.

Local site conditions will modify to some extent the accelerations and spectra developed assuming "firm ground". However, conditions at Torrance are generally fair to good, and areas of so-called "bad ground", such as are found in some areas of Compton and Long Beach, do not appear to be present within the City.

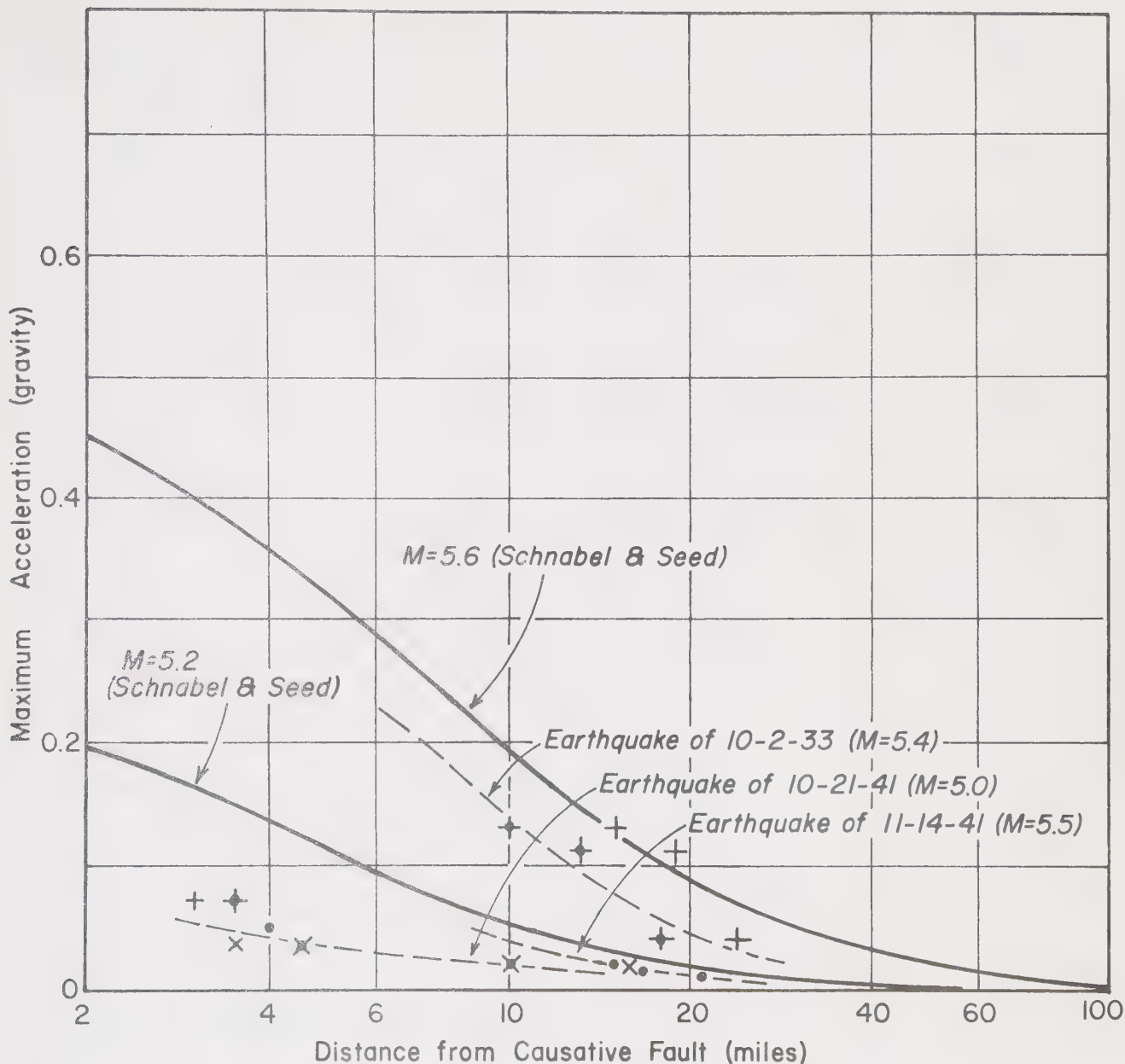
2. General Characteristics and Maximum Ground Acceleration for Firm Ground

a. Data from Local Earthquakes

Strong-motion accelerograph data applicable to the problem are listed in Table 8. The maximum values of acceleration (underlined in table) for each station during each of the four earthquakes are plotted on Figures 14 and 15 as a function of distance to the causative fault and

TABLE 8
SUMMARY OF ACCELEROGRAPH DATA FROM FOUR LOCAL
EARTHQUAKES, LOS ANGELES AREA, 1933-1941

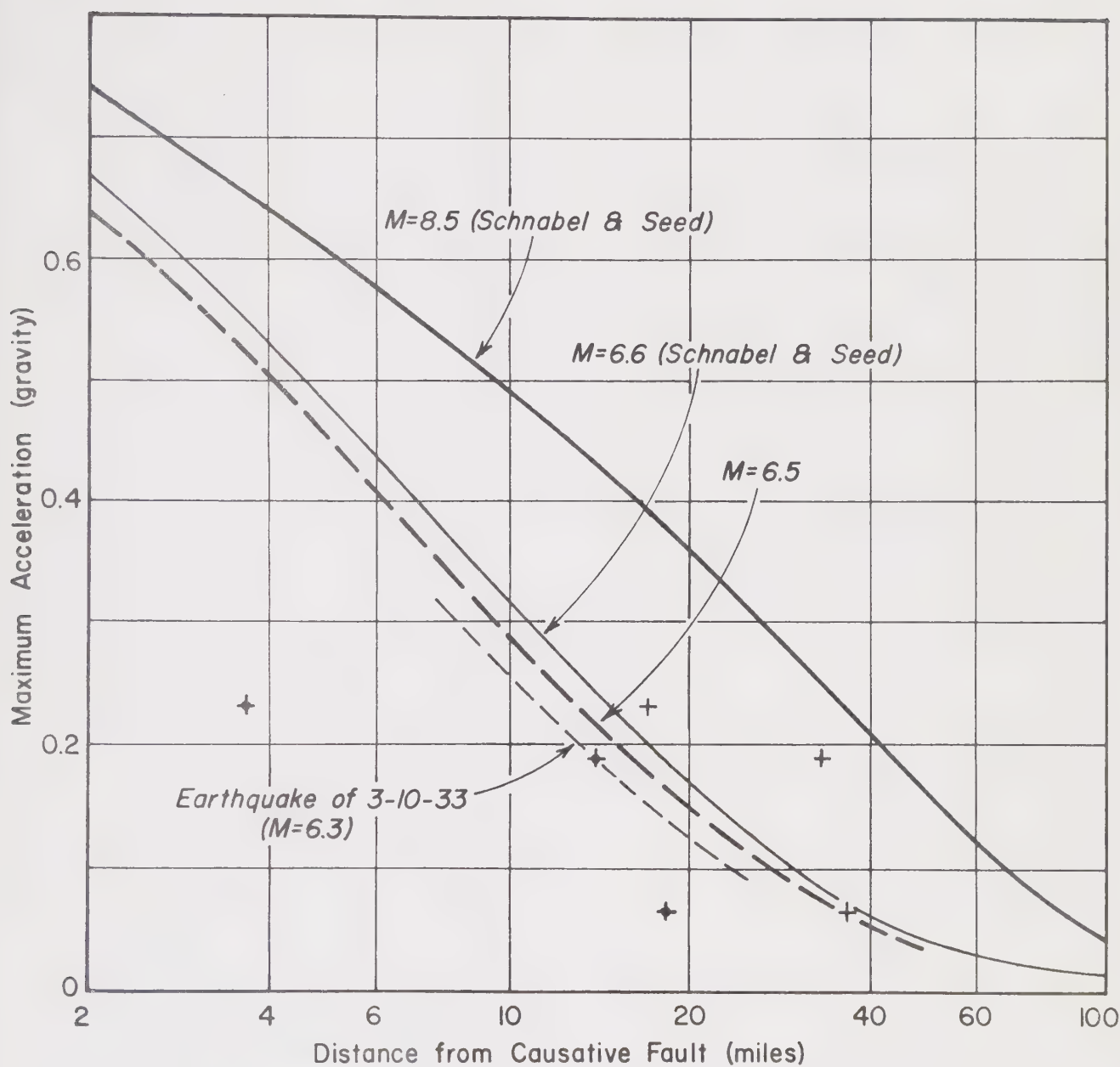
Earthquake and Station	Epicentral Distance (Miles)	Distance to Causitive Fault (Miles)	Maximum Acceleration (Gravity)	Period (Sec)	Displacement (In.)
<u>March 10, 1933 (Magnitude 6.3):</u>					
Long Beach	17	3.5	0.23	0.3	0.19
			0.11	1.5	2.4
Vernon	33	14	0.10	0.2	0.05
			0.15	0.7	0.75
			0.03	1.5	0.63
			0.03	2.5	1.5
			(0.19)	-	-
Subway Terminal	37	18	0.02	0.4	0.04
			0.05	0.6	0.20
			0.03	1.5	0.59
			(0.063)	-	-
<u>October 2, 1933 (Magnitude 5.4):</u>					
Long Beach	3	3.5	0.07	0.1	0.010
			0.025	0.5	0.063
Vernon	15	10	0.05	0.15	-
			0.13	0.13	0.10
Chamber of Commerce	19	13	0.11	0.2	0.04
Hollywood	24	18	0.038	0.45	0.07
<u>October 21, 1941 (Magnitude 5.0):</u>					
Long Beach	3.5	4.5	0.014	0.2	0.005
			0.032	0.5	0.07
			0.023	0.7	0.13
Chamber of Commerce	16	10	0.015	0.35	0.02
			0.013	0.5	0.04
			0.018	0.6	0.06
<u>November 14, 1941 (Magnitude 5.5):</u>					
Long Beach	4	-	0.033	0.2	0.01
			0.036	0.3	0.04
			0.049	0.65	0.21
Chamber of Commerce	17	-	0.008	0.25	0.005
			0.014	0.4	0.024
Vernon	15	-	0.019	0.12	0.003
			0.019	0.25	0.013
			0.008	0.4	0.015
Hollywood	21	-	0.002	0.1	0.004
			0.008	0.3	0.007
			0.002	0.5	0.005
Data is from United States Earthquakes, Neumann, 1935 and 1941 except as follows:					
1. Acceleration values in parenthesis are from analysis by Alford et al, 1964.					
2. Distance to Causitive Fault is determined from isoseismal maps, Figures 4 through 7.					
Locations of accelerograph stations are shown on Figures 4 through 7 as follows:					
lb Long Beach	st Subway Terminal		v Vernon		
cc Chamber of Commerce	h Hollywood				



MAXIMUM ACCELERATIONS IN ROCK for EVENTS $M=5.2$ & 5.6

- ✦ Event of 10-2-33, plotted distance to causative fault.
- ✦ Event of 10-2-33, plotted distance to epicenter.
- ✕ Event of 10-21-41, plotted distance to causative fault.
- ✕ Event of 10-21-41, plotted distance to epicenter.
- Event of 11-14-41, plotted distance to epicenter.

Figure 14.



MAXIMUM ACCELERATIONS IN ROCK for EVENTS $M=6.5$ & 8.5

- † Event of 3-10-33, plotted distance to causative fault.
- + Event of 3-10-33, plotted distance to epicenter.

Figure 15.

also epicentral distance. Because of problems of establishing the causative fault segment for the Torrance-Gardena (11-14-41) earthquake, these values are plotted only as a function of epicentral distance.

From this local data, acceleration vs distance curves (dashed curves on Figures 14 and 15) have been interpreted for the four earthquakes. In interpreting these curves, some of the data points have been ignored, and some reliance has been placed on the theoretical curves (solid lines) in establishing the general form for the dashed curves. The theoretical curves will be discussed in detail in the next section, and an explanation of the data points not used is given below.

The data from the Long Beach records have been ignored in developing the curves for the Long Beach earthquake (3-10-33), the Signal Hill earthquake (10-2-33), and the Torrance-Gardena earthquake (11-14-41). Of these, the records for the March 10, 1933 earthquake are the most important. This earthquake was the first real test of the strong motion instruments, and the horizontal components of the Long Beach record could not be read accurately because of the high frequencies and overlapping of the three traces. Tracings of the vertical component and the north-south component after 5.5 seconds are shown on Figure 16.

In an article published less than a month after the earthquake, Heck (1933) stated that "...for the first seven seconds there are vibrations on the order of 0.1 sec, with accelerations from 0.3 to 1.0g, perhaps a little more." An article about two months later (Heck and Neumann, 1933) omits all mention of such large accelerations.

Other evidence suggesting higher horizontal accelerations than those recorded in Table 8 is the high vertical acceleration of 0.25g recorded at approximately 3 seconds. Horizontal accelerations are normally several times greater than the vertical accelerations. This general

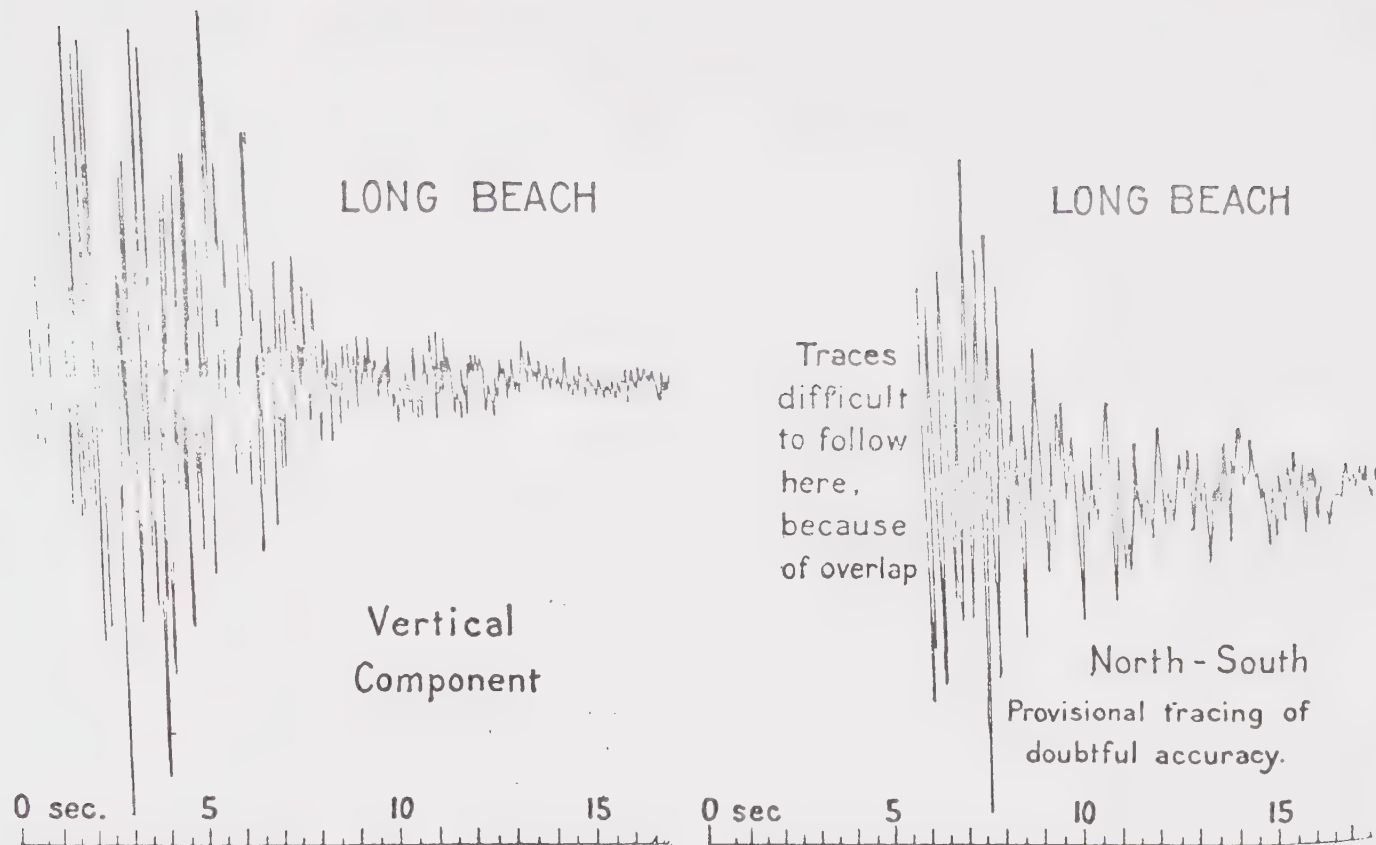


Figure 16. Tracings of the readable parts of the accelerograms from the Long Beach station recorded during the Long Beach earthquake of March 10, 1933. From Heck and Neumann, 1933.

relationship suggests a value of 0.5g or even the 1.0 g reported the month after the earthquake.

The reason the values from Long Beach are low for the other two earthquakes is not clear. The Long Beach records have not been studied in detail as have the Vernon and Subway Terminal records (see Appendix C). More recent work, discussed in the next section, indicates the Long Beach values are too low for 3 and possibly all 4 earthquakes.

b. Data from Other Sources

The solid lines on Figures 14 and 15 are curves derived by Schnabel and Seed (in press) based on both recorded data and on theoretical considerations. Previous studies (e.g., Seed et al, 1969) have presented useful relationships for distances from the "center" of the earthquake of 15 miles or more, but have been weak for areas close to the source. Since all of Torrance is within 10 miles of the Newport-Inglewood fault zone, this most recent study is particularly important. The title, "Accelerations in Rock...", suggests that the results are applicable to firmer ground than that at Torrance. However, comparison of the critical data used and the characteristics of the recording sites (e.g. Maley, 1970) indicates that the study is also applicable to areas of "firm ground" and to Torrance with relatively minor modification.

Comparison of the curves of Schnabel and Seed with those derived from data recorded during local earthquakes (Figures 14 and 15) indicates reasonably good agreement of the acceleration/distance functions. The only significant misfit is the curve for the Torrance-Gardena earthquake of 11-14-41. This earthquake has been assigned a magnitude of 5.5, but it fits the other available data best as a magnitude 5.1 to 5.2 quake. The reasons for this are not clear, but it is not unusual for magnitudes to be "adjusted" by amounts in this range when studied in detail.

c. Zonation for Firm Ground

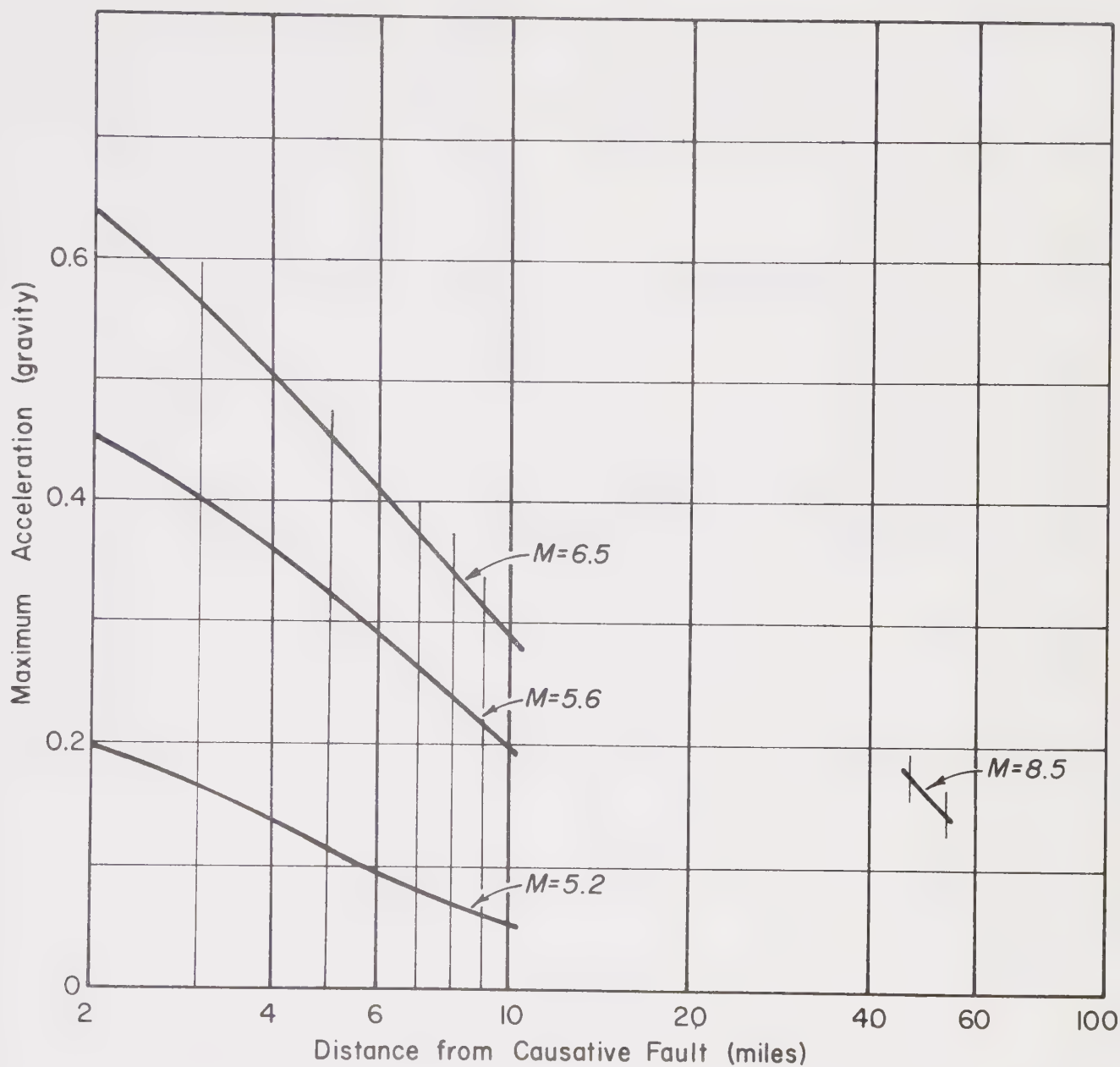
The acceleration/distance functions from Figures 14 and 15 for the expected events, magnitudes 5.2, 5.6 and 6.5 from the Newport-Inglewood fault zone and magnitude 8.5 from the San Andreas fault zone, are shown on Figure 17 for the applicable distances for Torrance. The San Andreas event (M=8.5) is at a sufficiently large distance that the applicable accelerations can be considered as constant for the City. The accelerations expected from the Newport-Inglewood fault zone, however, vary by a factor of about 2 within the City, and will be considered on a zone basis. It is emphasized, however, that this variation is continuous, and that the boundaries between zones are arbitrary.

In addition to the variations in shaking characteristics due to distance, local variations in rock and soil types will also affect the shaking expected. Richter (1959) has divided the Los Angeles Basin into four zones of probable maximum intensity of shaking based on rock or soil type.

Richter's microregionalization zones are as follows:

<u>Probable Maximum Intensity (M. Mercalli)</u>	<u>Previling Geological Character</u>
IX	Quaternary alluvium and sand dunes; landslide areas
VIII	Quaternary, consolidated
VII	Tertiary sediments and volcanics
VI	Granitic and Mesozoic sediments and metamorphics

These generalized relationships of 1) a lower intensity on the Tertiary sediments of the Palos Verdes Hills and, 2) a higher intensity in the sand dune areas near the coast are also apparent in the isoseismal maps (particularly Figures 4 and 6) of the local earthquakes discussed previously.



MAXIMUM ACCELERATIONS IN ROCK AND "FIRM GROUND"

CITY OF TORRANCE

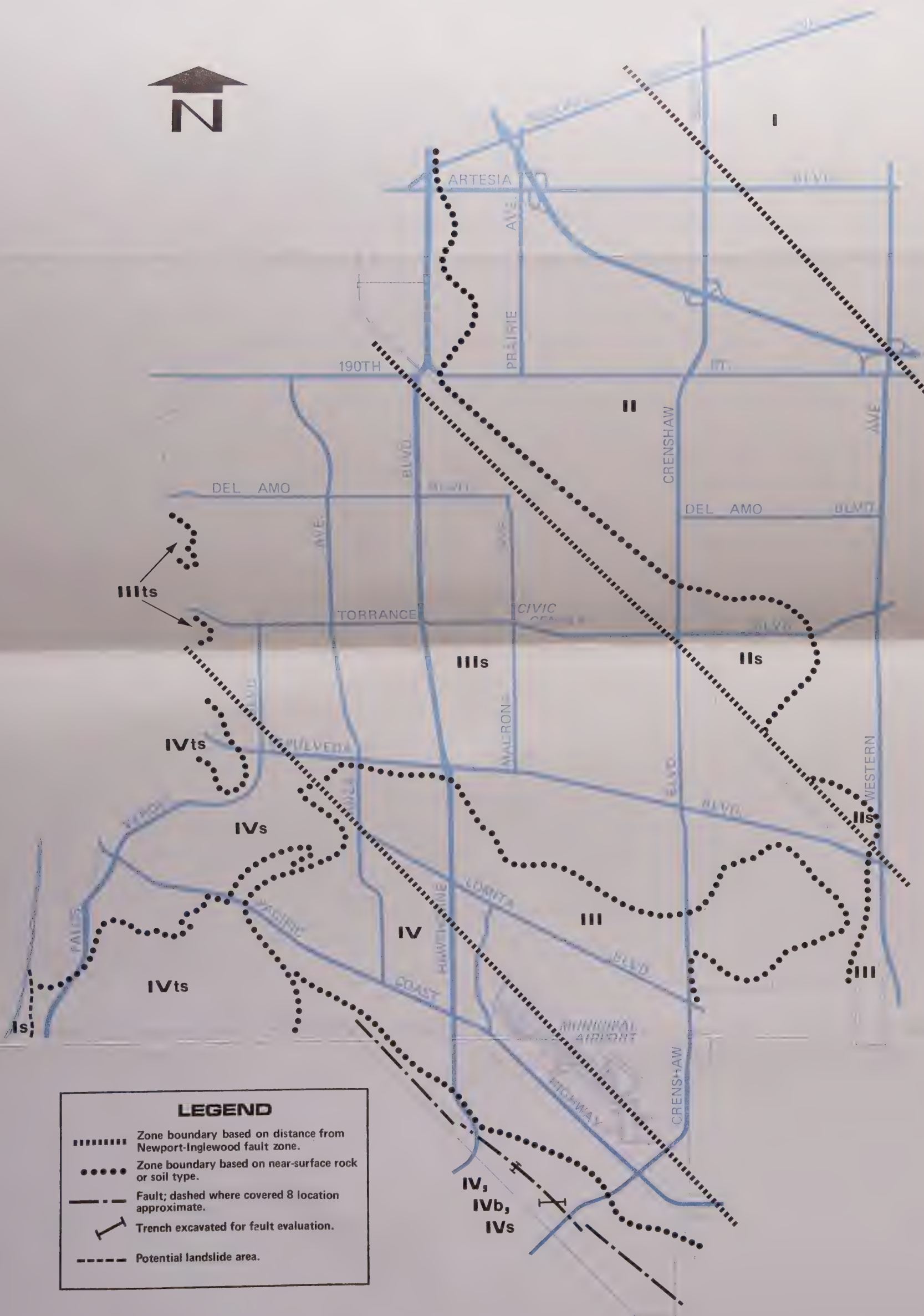
Figure 17.

Zonation of the City of Torrance as based on the distance from the Newport-Inglewood fault zone and the major types of near-surface rocks and soils is shown in Table 9, and the areal distribution of the zones are shown as Figure 18.

TABLE 9
SEISMIC ZONES IN THE CITY OF TORRANCE

Rock or Soil Type

Distance from the Newport-Inglewood Fault Zone in Miles		Tertiary	Firm Alluvium	Sand Dunes	
				Up to 140' above water table	More than 140' above water table
2-3			I		
3-5			II	II _s	
5-7			III	III _s	III _{ts}
7-9	IV _b		IV	IV _s	IV _{ts}



MAP OF SEISMIC ZONES

CITY OF TORRANCE

d. General Characteristics of Expected Earthquakes for Each Zone

The general characteristics of the expected earthquakes for each zone are given in Table 10. The characteristics given are maximum ground acceleration (a), predominant period (T), and duration of strong shaking (t). The numerical values assigned to each zone are based on data in Table 8, accelerograms, some of which are included in Appendix C, and the following general relationships:

The maximum acceleration on firm ground is taken from Figure 17 using the value at the mid-point of each zone. Based on a somewhat discounted version of Richters relationships, the maximum acceleration in the sand dunes can be expected to increase by a minimum of approximately 25%, and to decrease by a similar amount in the bedrock areas of the Palos Verdes Hills.

The predominant period on firm ground will vary from approximately 0.2 sec for the magnitude 5.2 event to approximately 0.4 to 0.5 sec for the magnitude 8.5 event (Seed, et al, 1969). It will increase slightly with increasing distance, and will be affected significantly by changes in rock or soil types. The latter is discussed in more detail in the next section.

The duration of strong shaking increases primarily with increase in magnitude (Housner, 1970, Table 4.3), but will also increase to a lesser extent where the natural period of the rock or soil type approximates the dominant period of the incoming bedrock motion.

TABLE 10
GENERAL CHARACTERISTICS OF EXPECTED EARTHQUAKES

Zone	Magnitude of Earthquake on the Newport-Inglewood Fault Zone			San Andreas Fault Zone
	5.2	5.6	6.5	8.5
I	a = 0.2g T = 0.1-0.2 sec t = 2-5 sec	a = 0.45g T = 0.2-0.3 sec t = 5-8 sec	a = 0.64g T = 0.3 sec t = 10-15 sec	a = 0.18g T = 0.4-0.5 sec t = 30-40 sec
II	0.14g 0.1-0.2 sec 2-5 sec	0.36g 0.2-0.3 sec 5-8 sec	0.5g 0.3 sec 10-15 sec	0.18g 0.4-0.5 sec 30-40 sec
IIIs	0.17g 0.2-0.3 sec 4-6 sec	0.45g 0.3-0.4 sec 6-10 sec	0.7g 0.4-0.6 sec 15-20 sec	0.22g 0.6-0.8 sec 40-50 sec
III	0.1g 0.2 sec 4-6 sec	0.28g 0.2-0.3 sec 6-10 sec	0.42g 0.3-0.4 sec 15-20 sec	0.18g 0.4-0.5 sec 30-40 sec
IIIIs	0.12g 0.2-0.3 sec 6-8 sec	0.35g 0.3-0.4 sec 10-15 sec	0.53g 0.4-0.6 sec 15-20 sec	0.22g 0.6-0.8 sec 40-50 sec
IIIIts	0.12g 0.3-0.4 sec 6-8 sec	0.35g 0.4-0.6 sec 15-20 sec	0.53g 0.5-0.8 sec 20-25 sec	0.22g 0.7-1.0 sec 50-60 sec
IV	0.07g 0.2 sec 4-6 sec	0.23g 0.2-0.3 sec 6-10 sec	0.35g 0.3-0.4 sec 15-20 sec	0.18g 0.4-0.5 sec 30-40 sec
IVb	0.05g 0.1-0.2 sec 2-5 sec	0.17g 0.2-0.3 sec 4-8 sec	0.25g 0.2-0.3 sec 8-12 sec	0.14g 0.3-0.4 sec 20-30 sec
IVs	0.1g 0.2-0.3 sec 6-8 sec	0.3g 0.3-0.4 sec 10-15 sec	0.45g 0.4-0.6 sec 15-20 sec	0.22g 0.6-0.8 sec 40-50 sec
IVts	0.1g 0.3-0.4 sec 6-8 sec	0.3g 0.4-0.6 sec 15-20 sec	0.45g 0.5-0.8 sec 20-25 sec	0.22g 0.7-1.0 sec 50-60 sec
a = maximum ground acceleration (gravity) T = predominant period (sec) t = duration of strong shaking (sec)				

3. Generalized Response Spectra for Firm Ground

a. Availability of Data

Two accelerographs have recently been installed in the Golden West Towers, and another station has been in operation for a longer time at 2516 Via Tejon in Palos Verdes Estates. However, neither station was in operation during any of the four local earthquakes of significance to this investigation

The principal sources of local information have been the records made in Los Angeles at Vernon, Subway Terminal, Chamber of Commerce and Hollywood. (Locations shown on Figures 4 through 7.) As discussed previously, the records from the Long Beach station do not appear to fit well with other data. Of the above stations, spectra are available for the Vernon and Subway Terminal sites for the March 10, 1933, Long Beach earthquake, and the October 2, 1933, Signal Hill earthquake. These are included as Appendix C.

In addition to local data, the spectra of records from the 1966 Parkfield earthquake have been used. This network of data is particularly useful because accelerographs were located at distances of 0, 3.4, 6, and 9.5 miles from the causative fault during this magnitude 5.6 event.

The most significant gap in the data is the lack of even one strong-motion record for a "great" earthquake such as that expected from the San Andreas fault zone. The closest substitute available is the record of the Kern County earthquake, magnitude 7.6, from Taft approximately 35 miles from the source.

Modifications of spectra for local conditions are based on studies of near-surface amplification at accelerograph and seismoscope sites by Duke et al (1962) and Matthiesen et al (1964). Amplification parameters

for the sites of the accelerograph data used in developing spectra for Torrance are given in Table 11. Near-surface conditions for the Cholame accelerograph stations are from Maley (1970).

TABLE 11
AMPLIFICATION PARAMETERS

(From Matthiesen et al, 1964)

Location	Factor for Short Periods	Transition (Seconds)	Factor for Long Periods
<u>Data for Specific Sites:</u>			
Harbor City ¹	10	1.1	5
Hyperion ²	10	1.0	5
Vernon	12	1.0	3
Subway Terminal	10	1.35	3
Taft	12	0.5	3
<u>Relationships Determined from the Above Data:</u>			
Torrance (general)	10	1.0-1.1	3
Torrance/Vernon	0.83	1.0-1.1	1.66
Torrance/Subway Terminal	1.0	1.1-1.35	1.66
Torrance/Taft	0.83	0.5-1.0	1.66

¹Narbonne High School, 1 block east of Torrance City limits.

²4.8 miles northwest of intersection of Hawthorne Ave. and Redondo Beach Blvd.

b. Generalized Response Spectra for Expected Earthquakes

Response spectra for the earthquakes expected at Torrance have been derived by the following method:

1. Spectra from an earthquake, or earthquakes, of similar magnitude, recorded at similar distances, and, if possible, recorded at a site with similar near-surface characteristics, are smoothed and plotted as a function of period on the tripartite logarithmic graph paper.
2. Adjustments in response for variations in site characteristics are made using the data in Table 11.
3. Spectra for specific distances from the expected source of the earthquake are interpolated from the adjusted spectra. The distances used are the mid-points of the four basic seismic zones (I - IV).

The smoothing of the original spectra is necessary because individual "highs" and "lows" are probably not applicable over the large areas included in the zones at Torrance. More detailed and specifically applicable spectra can be obtained for important structures by detailed studies of individual sites. However, it should be kept in mind that the measured natural frequency of a structure may vary from its expected, theoretical value by as much as 100% (Housner and Brady, 1963). Also, it may increase by as much as 50% during an earthquake due to changes induced in the properties of the structure by the shaking.

The logarithmic graphs on which the spectra are presented are preferred over the older, linear graphs used in Appendix C because spectral acceleration, relative velocity and displacement can all be obtained from a single graph based on the approximate relationship

$$S_a \frac{T}{2\pi} = S_v = \frac{2\pi}{T} S_d$$

where:

T = period

S_a = spectral acceleration (absolute)

S_v = spectral velocity (relative)

S_d = spectral displacement (relative)

Spectra are derived for 0 and 5 percent of critical damping. The 0% damped spectra can be considered as an approximation of the Fourier amplitude spectra, or the energy available to shake structures having various natural periods (see Appendix A). The 5% critical damping was chosen because it is probably the most common damping constant applied in the analysis of structures.

Spectra derived by the methods discussed above are included for the expected earthquakes of magnitude 5.6 and 6.5 on the Newport-Inglewood fault zone, and magnitude 8.5 on the San Andreas fault zone. Spectra are not included for the magnitude 5.2 event because: 1) the shaking from an earthquake of this magnitude should be covered by building code (UBC) requirements except possibly in the extreme northeast corner of the City; 2) applicable data are not available from which to derive spectra for this event in this part of the City; and 3), the relatively limited use recommended for this expected event.

The spectra for the magnitude 5.6 event (Figures 19 and 20) are based on the spectra from Parkfield earthquake (M=5.6) and the Signal Hill earthquake (M=5.4). The spectra for the magnitude 6.5 event (Figures 21 and 22) are based primarily on the spectra from the Long Beach earthquake (M=6.3), and, to a lesser extent, on data from the

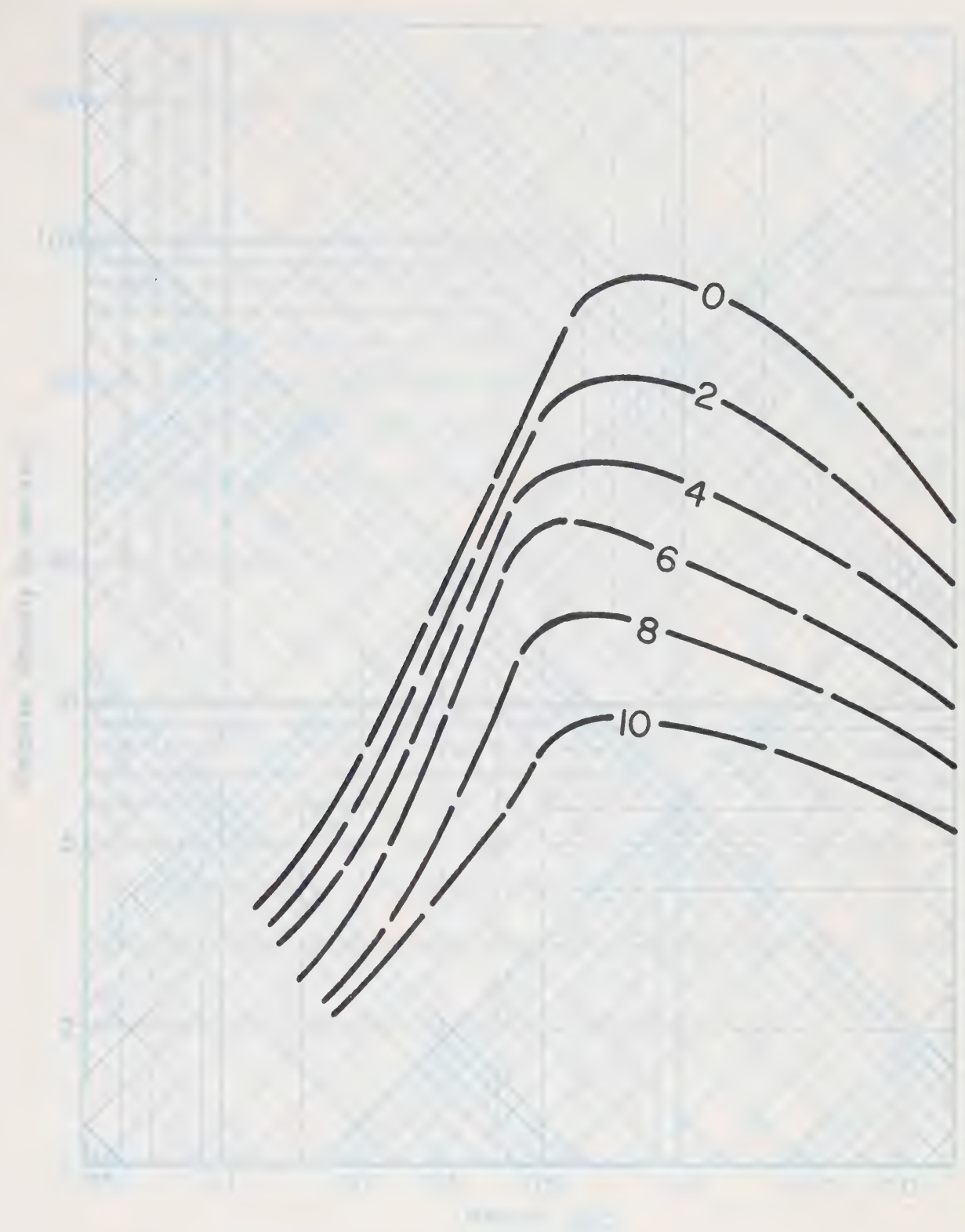


Figure 19. Response spectra (0% of critical damping) for earthquake of magnitude 5.6 on the Newport-Inglewood fault zone. Numbers on curves indicate distance from fault zone.

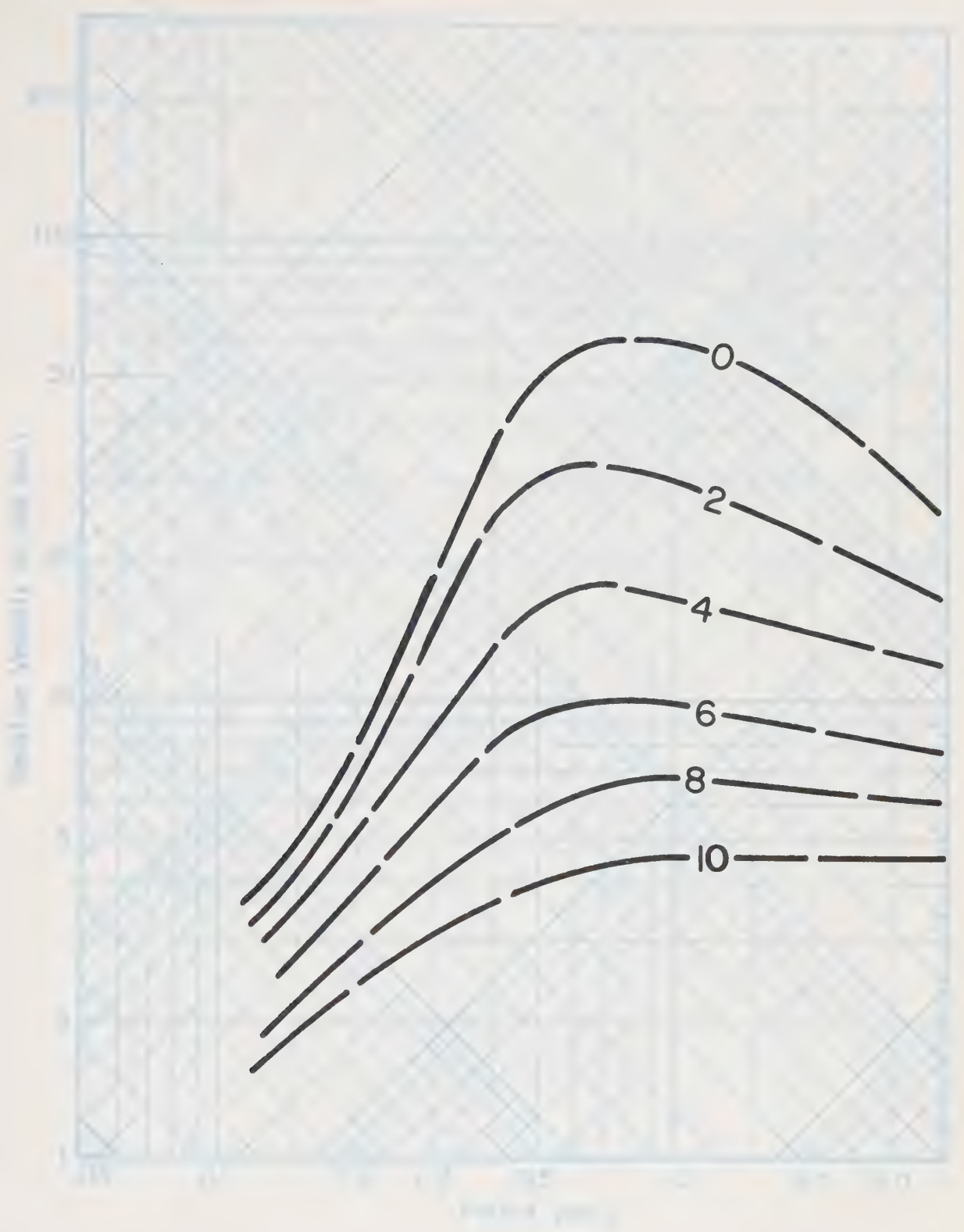


Figure 20. Response spectra (5% of critical damping) for earthquake of magnitude 5.6 on the Newport-Inglewood fault zone. Numbers on curves indicate distance from fault zone.

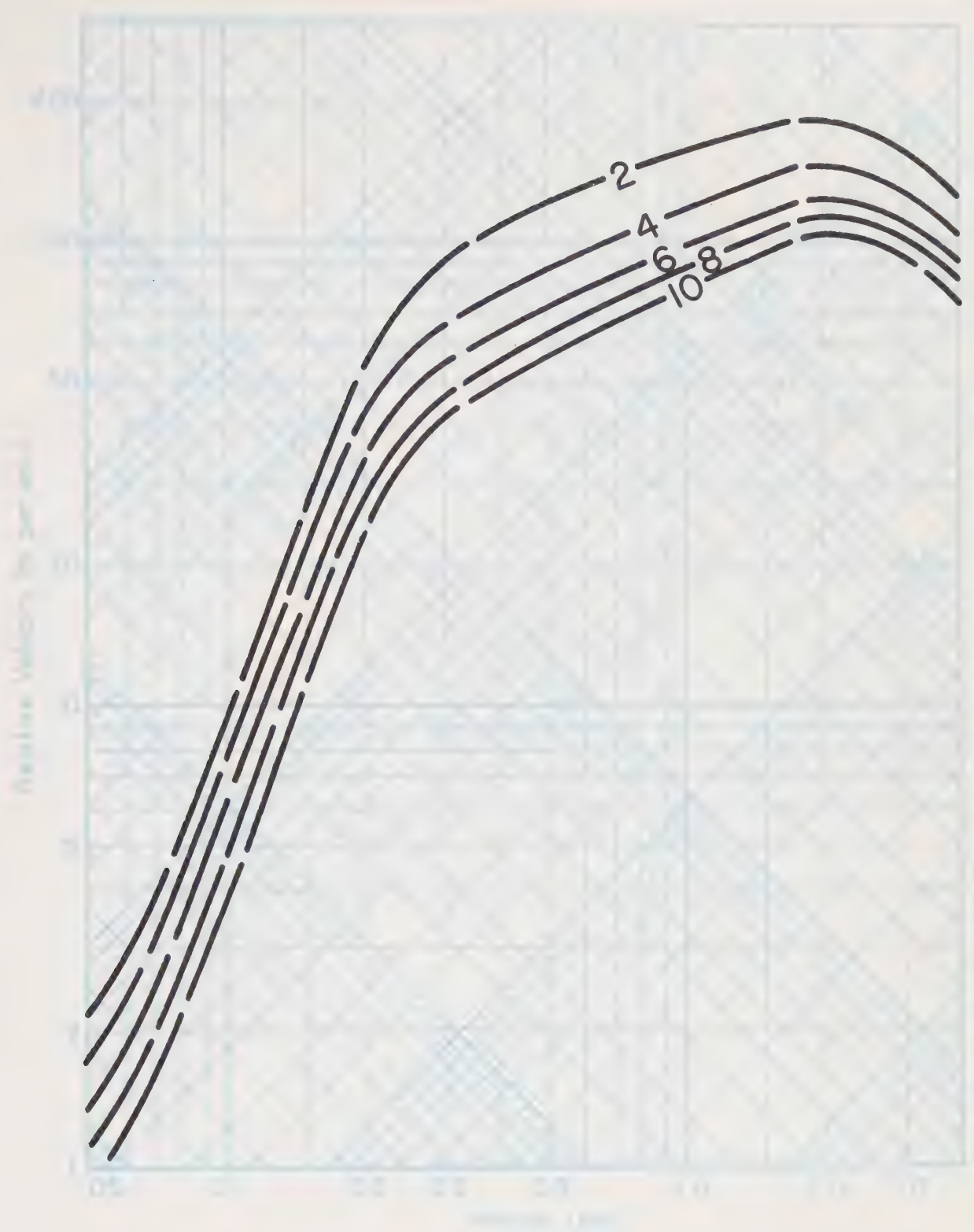


Figure 21. Response spectra (0% of critical damping) for earthquake of magnitude 6.5 on the Newport-Inglewood fault zone. Numbers on curves indicate distance from fault zone.

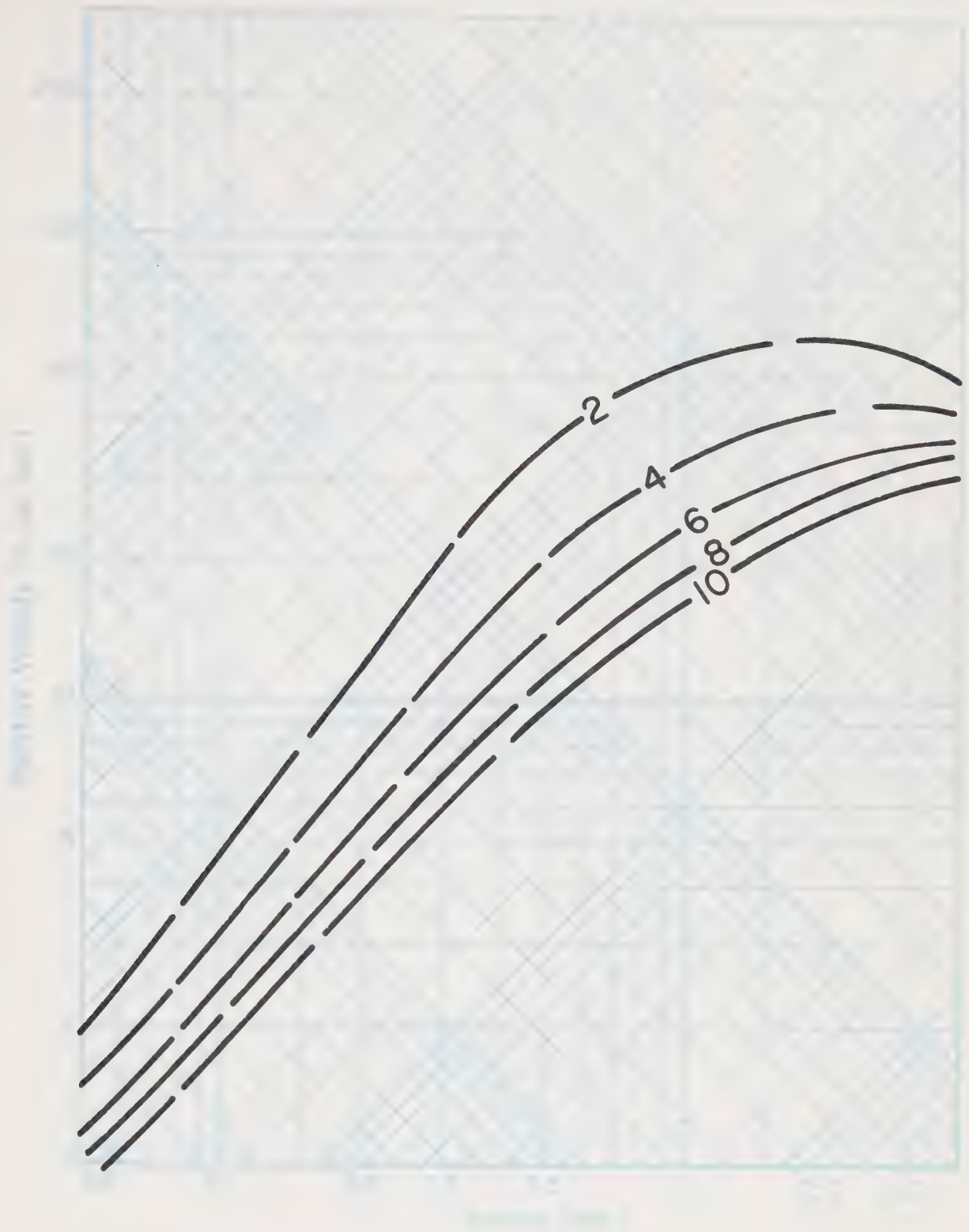


Figure 22. Response spectra (5% of critical damping) for earthquake of magnitude 6.5 on the Newport-Inglewood fault zone. Numbers on curves indicate distance from fault zone.

recent San Fernando earthquake ($M=6.4$). The spectra for the magnitude 8.5 event (Figure 23) are based on the Kern County earthquake ($M=7.6$). Records for larger earthquakes are not available.

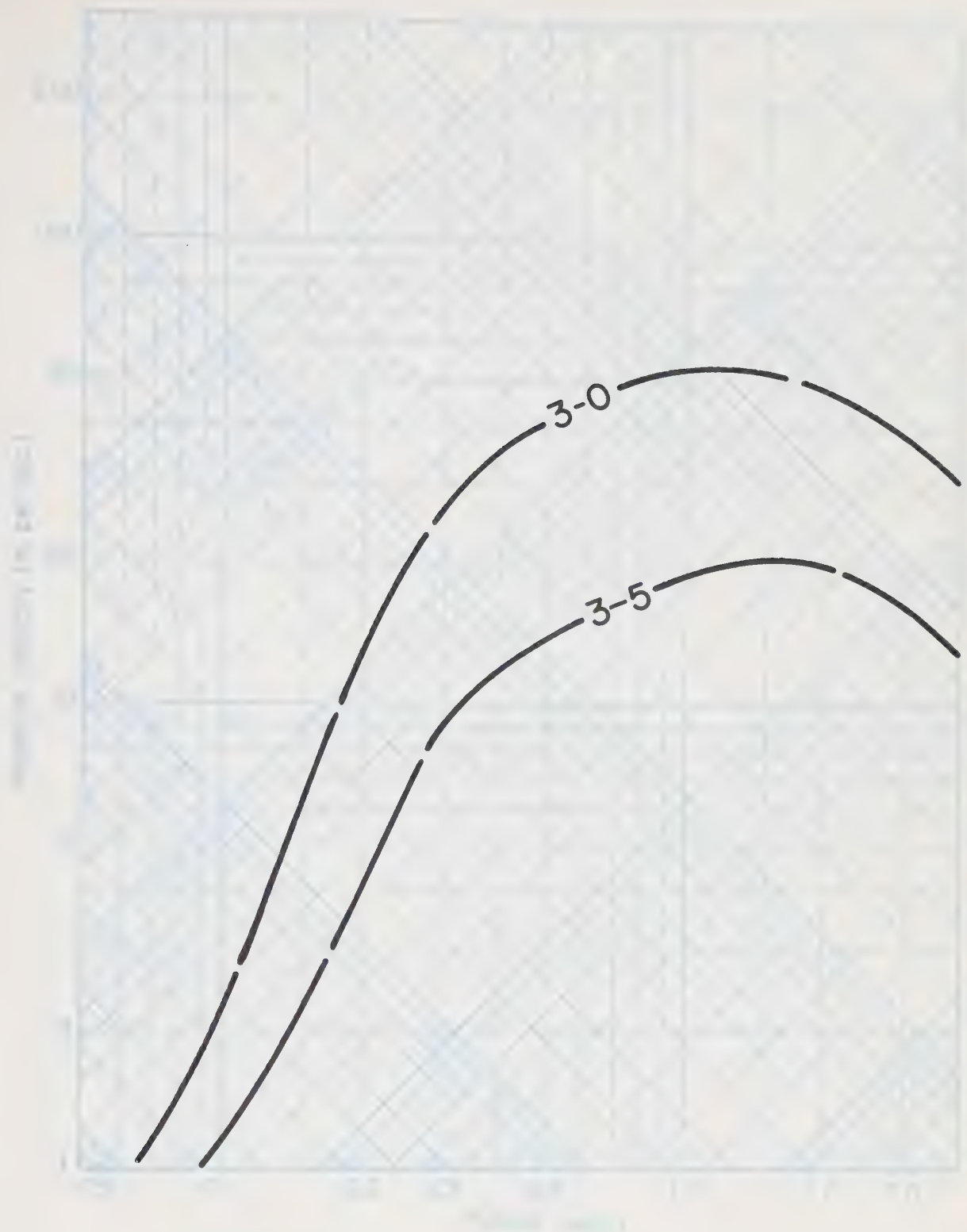


Figure 23. Response spectra for earthquake of magnitude 8.5 on the San Andreas fault zone. Curve 3-0 is for 0% of critical damping and curve 3-5 is for 5% of critical damping.

4. Variations Due to Local Conditions

a. Near-Surface Soil Conditions

Near-surface soils or rocks amplify the incoming earthquake waves as they move from the bedrock into the softer materials nearer the surface. As discussed in Appendix A, the relationship is essentially a conservation of energy in which the energy of velocity is transferred to energy of amplitude as the waves approach the surface. The basic relationships are shown diagrammatically in Figure 24, and are represented in the following equation (Matthiesen et al, 1964):

$$R = \frac{D_2 v_2}{D_1 v_1}$$

where

R = amplification ratio,

D = density, and

v = velocity.

In qualitative terms, as density and velocity decrease from layer 2 to layer 1, the amplification increases proportionally.

Data on near-surface soil and rock types and their distribution has been taken principally from Poland et al (1959), California Department of Water Resources (1968), and the logs of wells kindly made available by the Los Angeles County Flood Control District. Variations in physical characteristics and the resulting amplification factors are based on the work of Duke et al (1962) and Matthiesen et al (1964). Of particular significance to conditions at Torrance are the data from Narbonne High School, one block east of the Torrance City limits, and Hyperion, 4.8 miles northwest of Torrance. Both locations are seismoscope sites, and are not a source of accelerograph data.

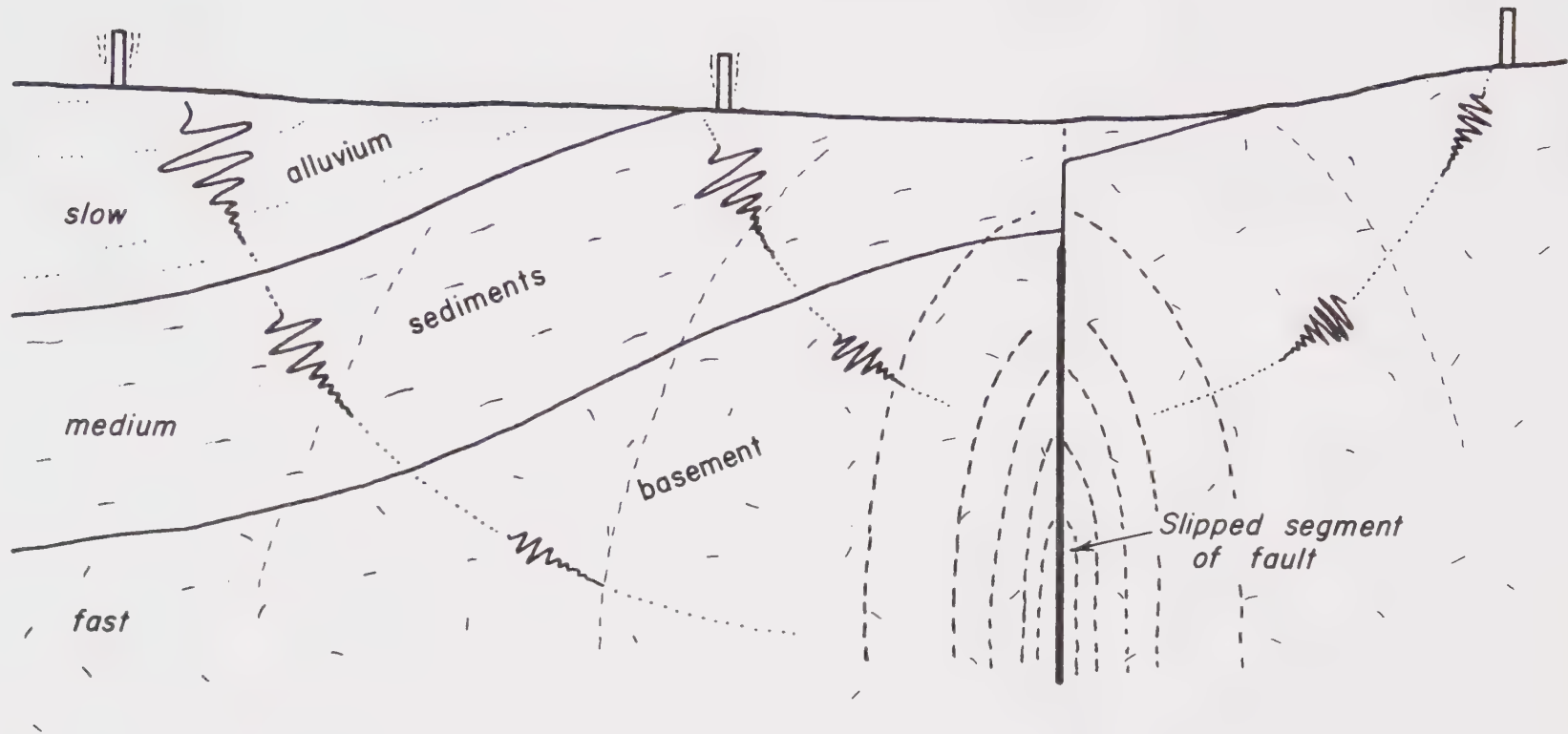


Figure 24. Diagrammatic cross section illustrating near-surface amplification of earthquake waves. Amplification of the waves amplitude is due primarily to a transfer of energy as the waves travel through slower rocks.

The Narbonne site is located on upper Pleistocene terrace material, and can be considered typical of areas underlain by this material in Torrance. The Hyperion site is in the area underlain by dune sand, but most of this material has been removed in grading the site. The result is a location more characteristic of the underlying upper Pleistocene sequence. The two sites have similar amplification characteristics (see Table 11), and together they can be considered as a good indication of conditions to be expected on the terrace deposits (Firm Alluvium in Table 9) in Torrance.

Dune sand is the most widespread surficial material in the City, and is the soil type underlying the high ridges along the coast and the northwest-trending low ridge near the center of the City. These old dunes are generally 40-60 feet thick, but in some areas, such as along Prospect Avenue near the west boundary of the City, they are as thick as 200 feet. They are dry (i. e. they are above the water table), have a relatively low density (average about 100 lbs/cu ft), and a P-wave velocity of about 600 ft/sec near the surface.

Alluvium is present in the southern part of the city near Lomita Boulevard and to the south near the Walteria sump. This material is relatively thin (5-10 feet) and does not represent a significant variation from the upper Pleistocene terrace material. A narrow tongue of alluvium is also present along the creek near the intersection of Torrance Boulevard and Western Avenue. This small area is not analyzed separately because it could not be developed to any extent without significant modification.

Bedrock (Malaga Siltstone) is present at some localities along the bluffs south of Pacific Coast Highway. This material is firmer, has a higher velocity, and will experience a lower amplitude of shaking.

b. Ground Water

The hydrograph (Figure 25) for a well near the southwest corner of the City is typical of the history of the fluctuations in the water table in the area. In the early 1900's the water table was slightly above sea level (Figure 26), but pumping for agricultural purposes gradually reduced the level to 10-20 feet below sea level by 1941 (Figure 27 and 28). Increased pumping during World War II and during the urbanization that followed, caused a rapid drop (Figure 25) in the water table to levels 40-60 feet below sea level. This drop strongly reversed the natural condition of a gradient toward the ocean, and salt water began intruding inland in response to this reversal. About 1964, the Los Angeles County Flood Control District began injecting fresh water near the coast to prevent further intrusion of salt water. As a result, the water table is now high near the coast (Figure 30), but still relatively low in eastern Torrance.

A comparison of velocity changes and the position of the water table in the study of site characteristics (Duke et al, 1962) indicates that the water table is one of the major velocity breaks affecting the frequency distribution of the amplification ratios. Figure 31 is a map of the depth to the water table except for the area south of Pacific Coast Highway where shallow bedrock and perched ground-water conditions are present. It has been constructed using Figure 30 and surface topography. Examination of the map indicates that the east-sloping water table and generally east-sloping topography combine to give a relatively constant depth to the water table over most of Torrance. Significant variations occur in western Torrance near Prospect Avenue, and near Calle Mayor where the depth exceeds 140 feet.

Figure 26.

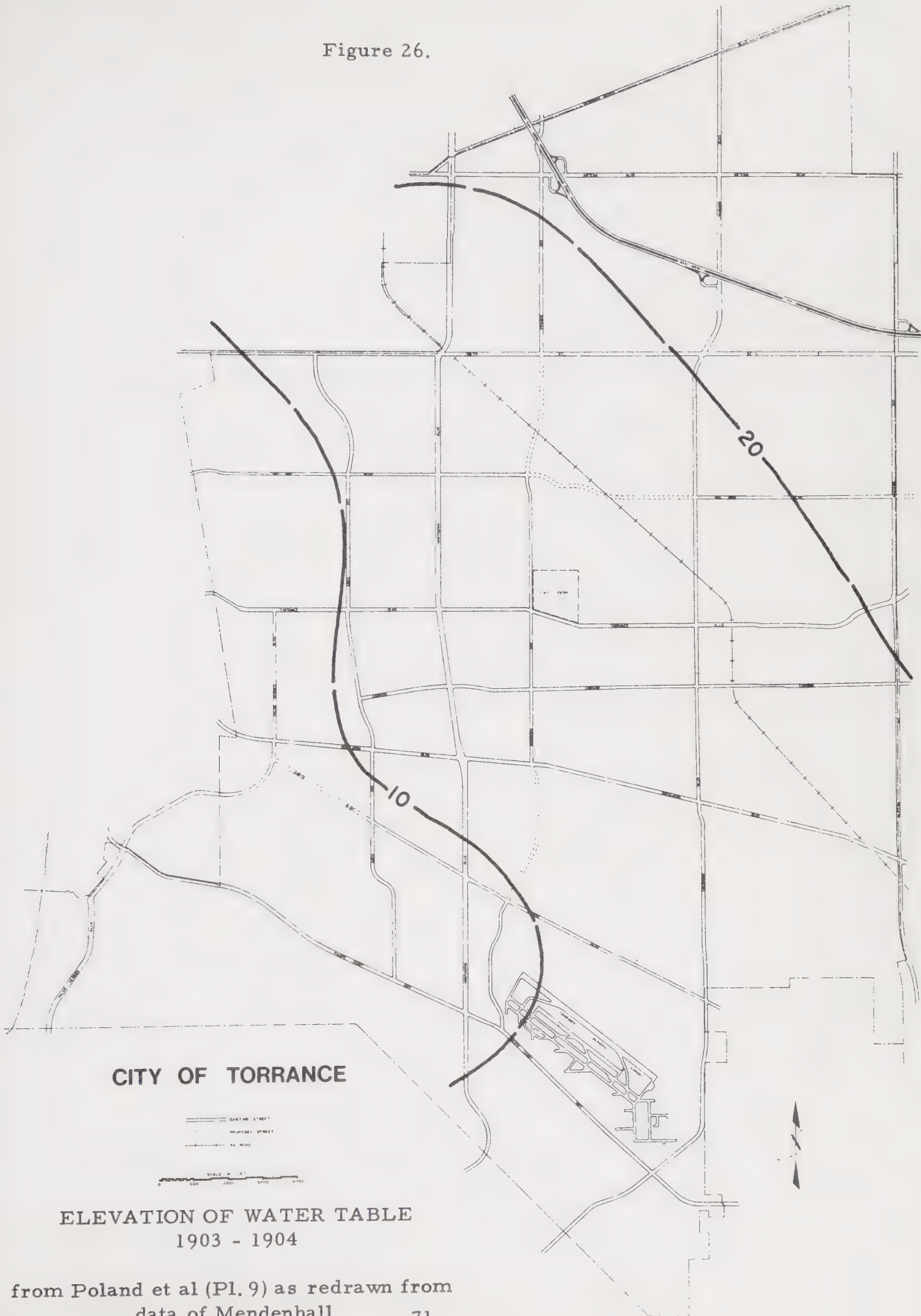


Figure 27.

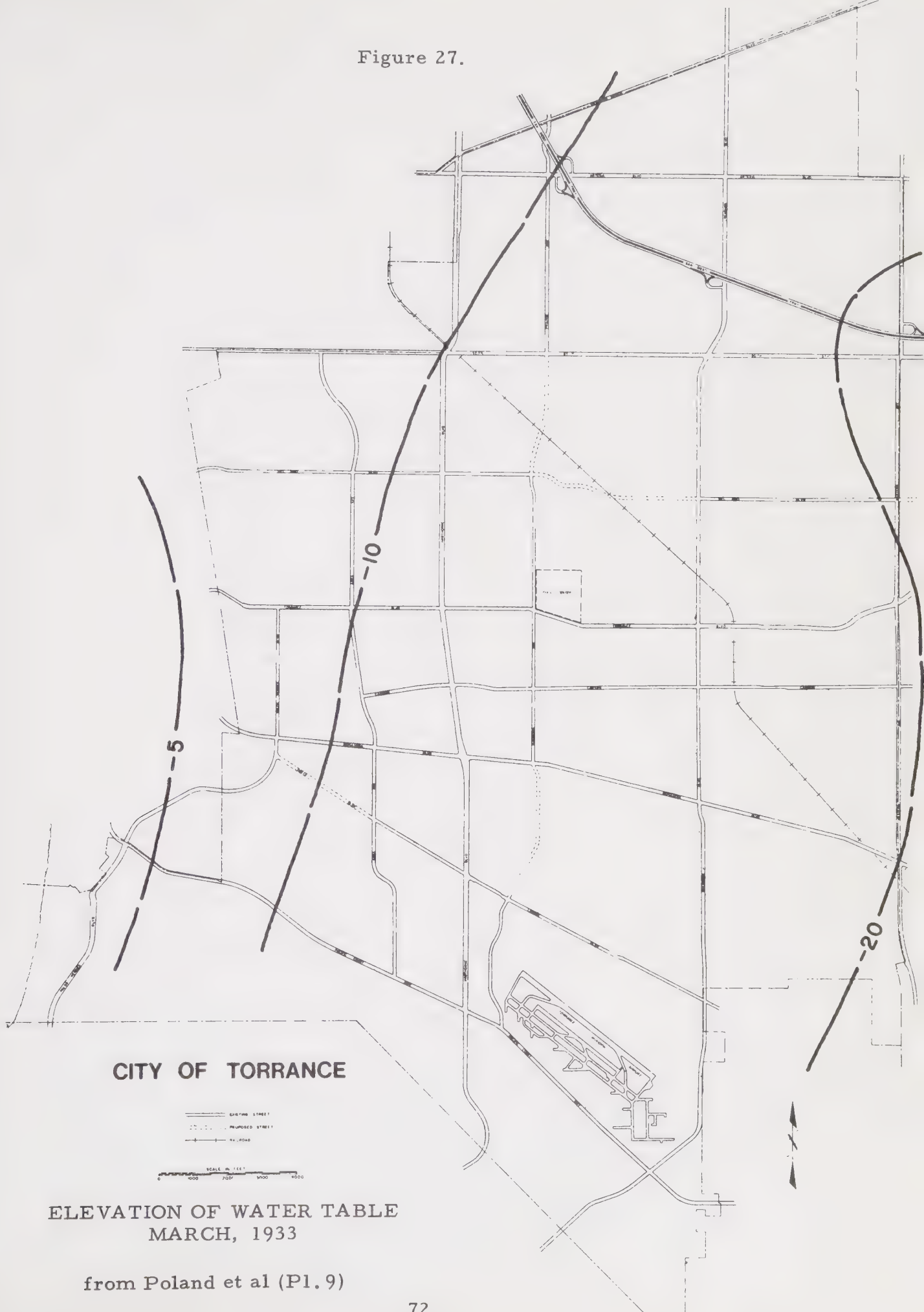


Figure 28.

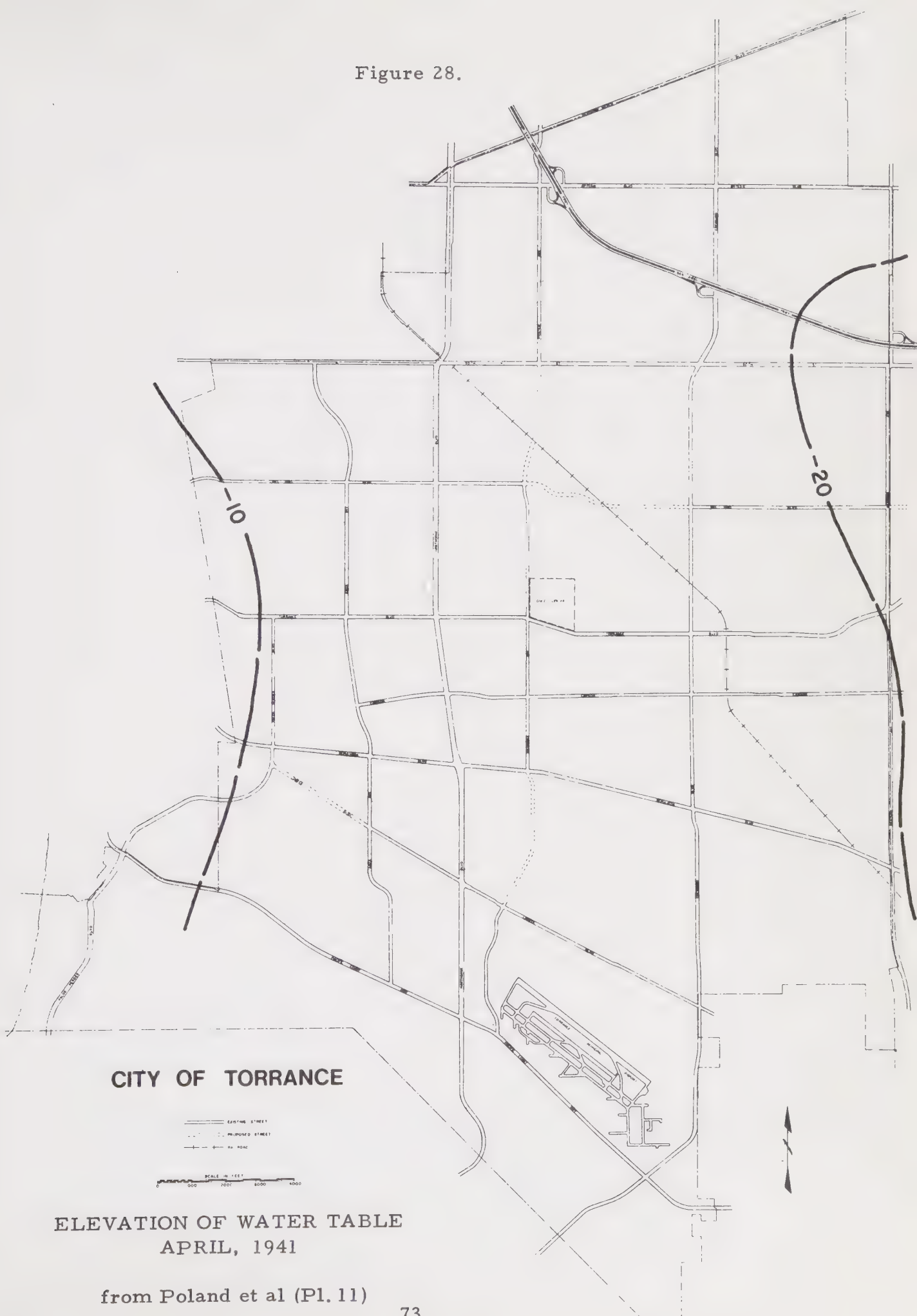
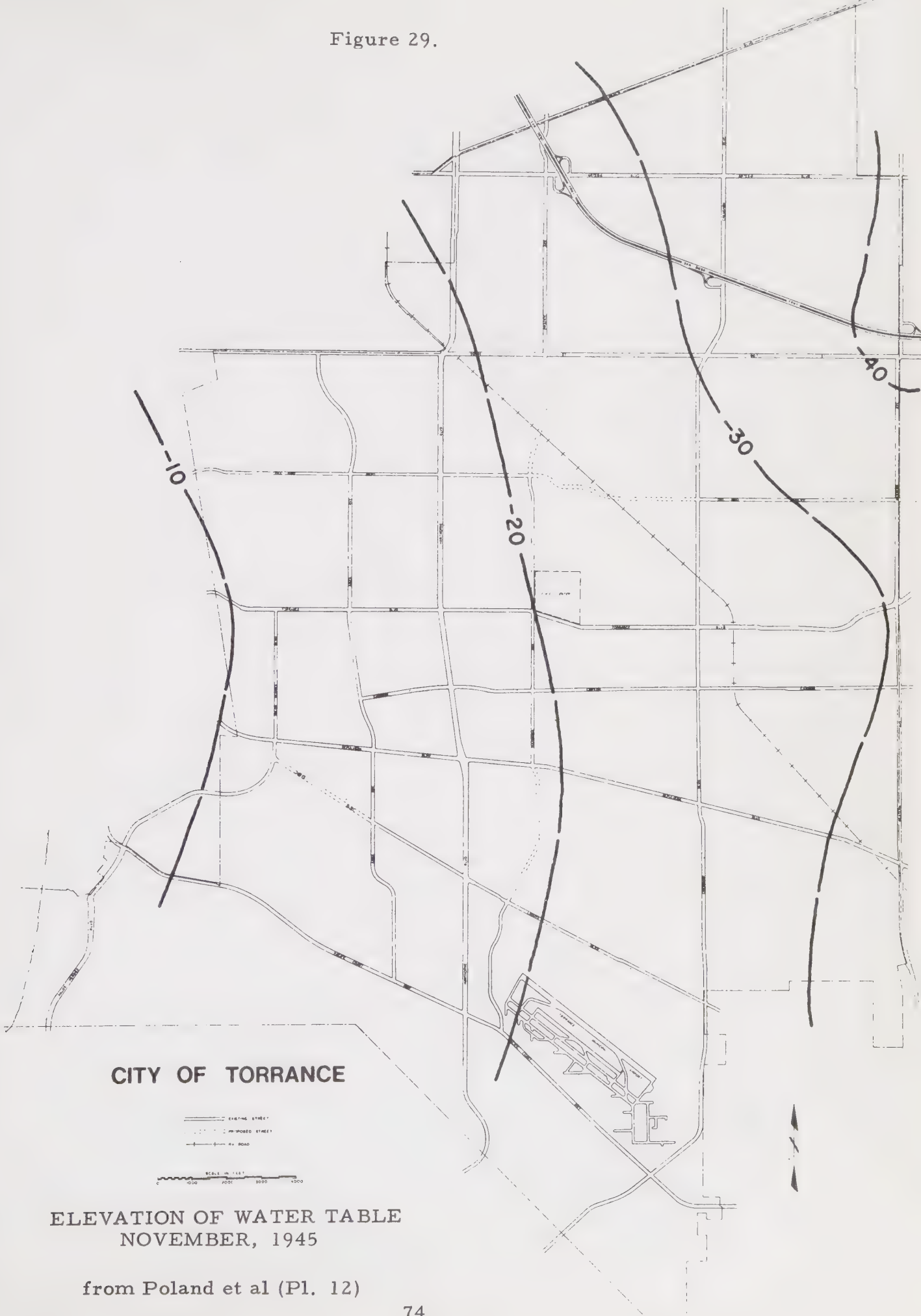


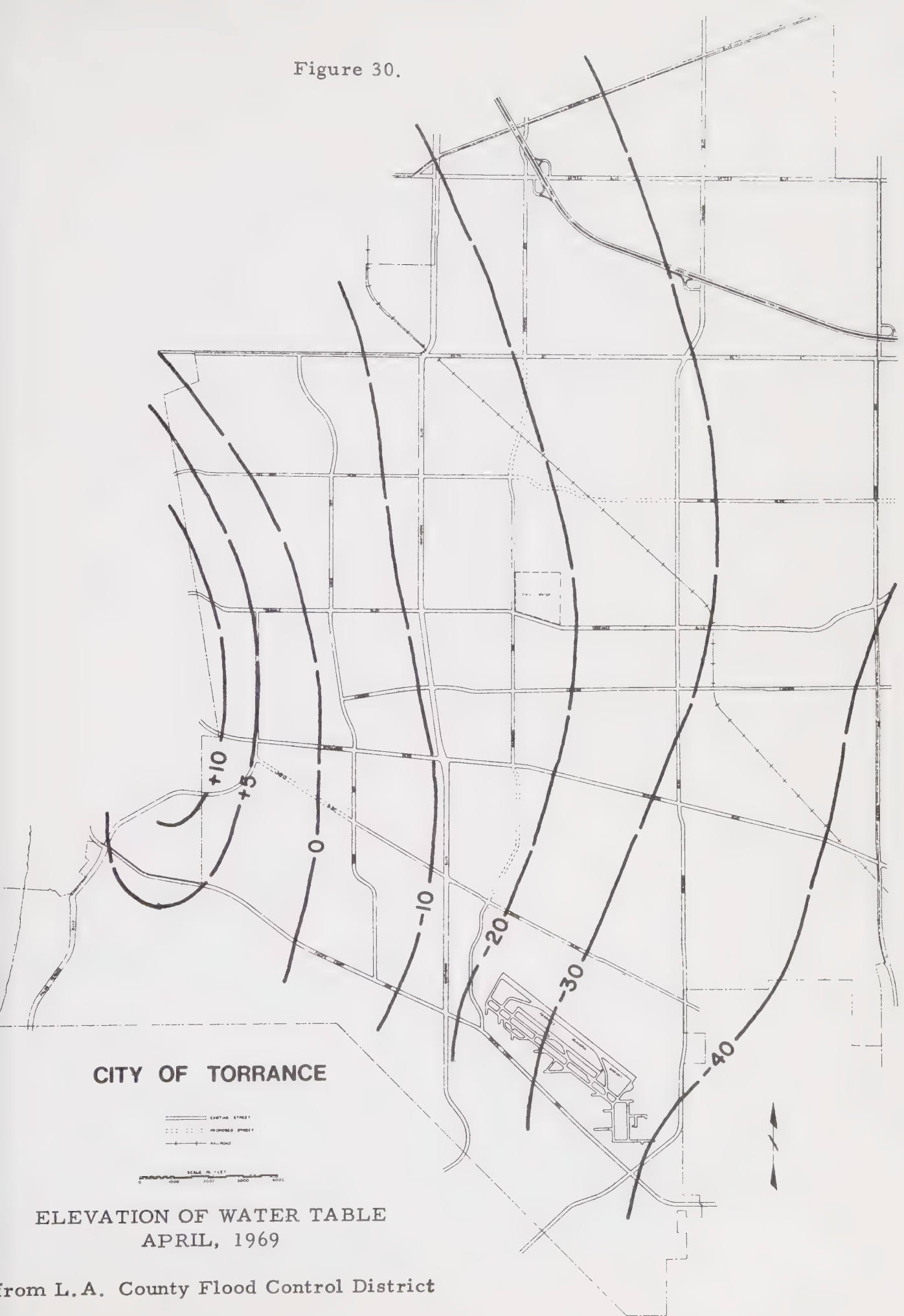
Figure 29.



ELEVATION OF WATER TABLE
NOVEMBER, 1945

from Poland et al (Pl. 12)

Figure 30.



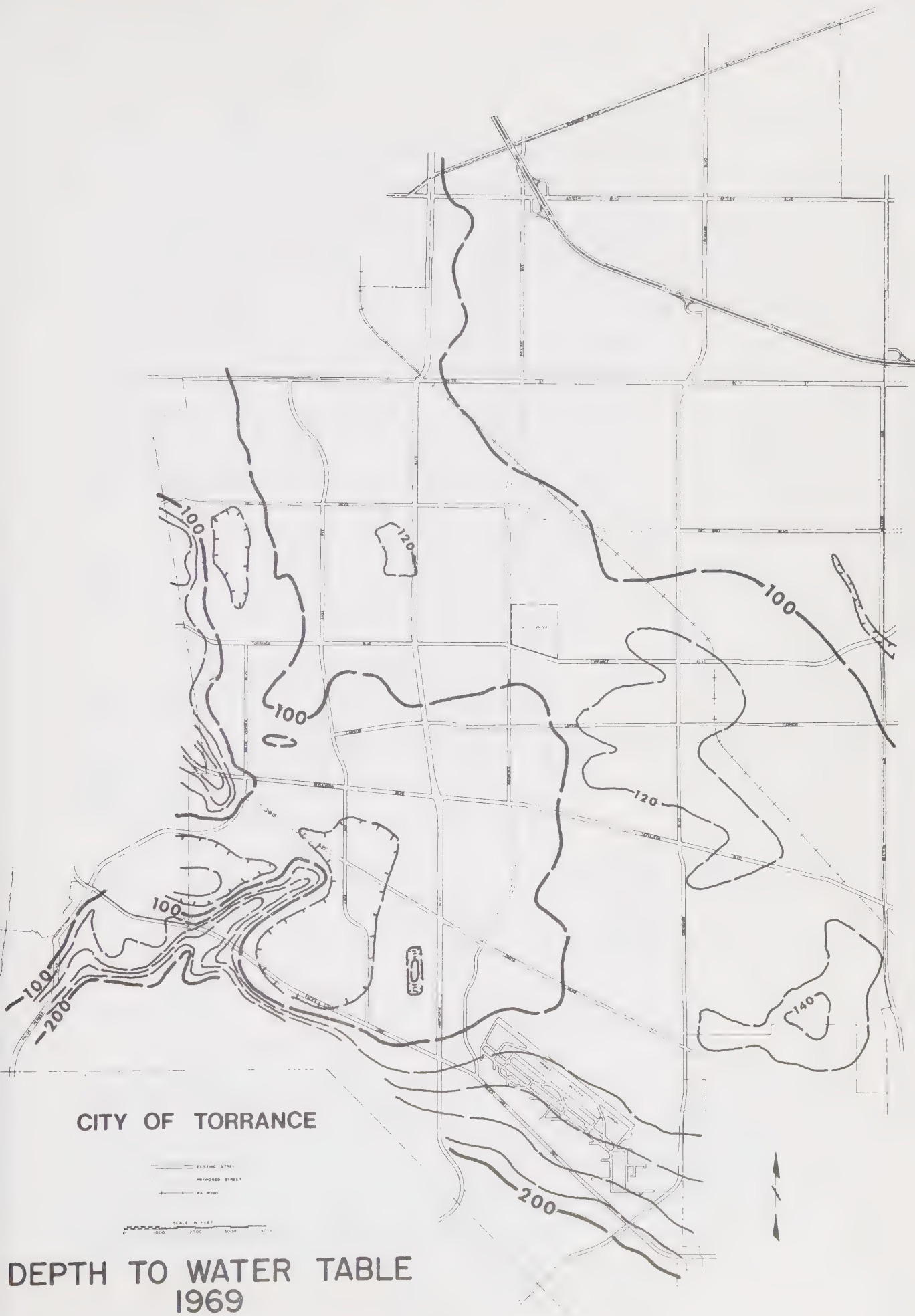


Figure 31.

c. Modification of Spectra for Local Conditions

Amplification parameters for the variations discussed above are given in Table 12. The values given should be considered approximate as they have been derived by using values from sites with similar rock and velocity characteristics. The short-period amplification factor from the Vernon site has been used for the dune sand areas, and the transition has been increased for the thicker sand areas assuming a shear-wave velocity below 140 feet and above the water table of 1000 feet/sec. The amplification parameters for areas of Tertiary bedrock are based on an apparent similarity with the Elysian Heights School site.

The amplification parameters in Table 12 have been used to modify the spectra for firm ground to derive spectra for all the zones. These spectra are included as Figures 32 through 41.

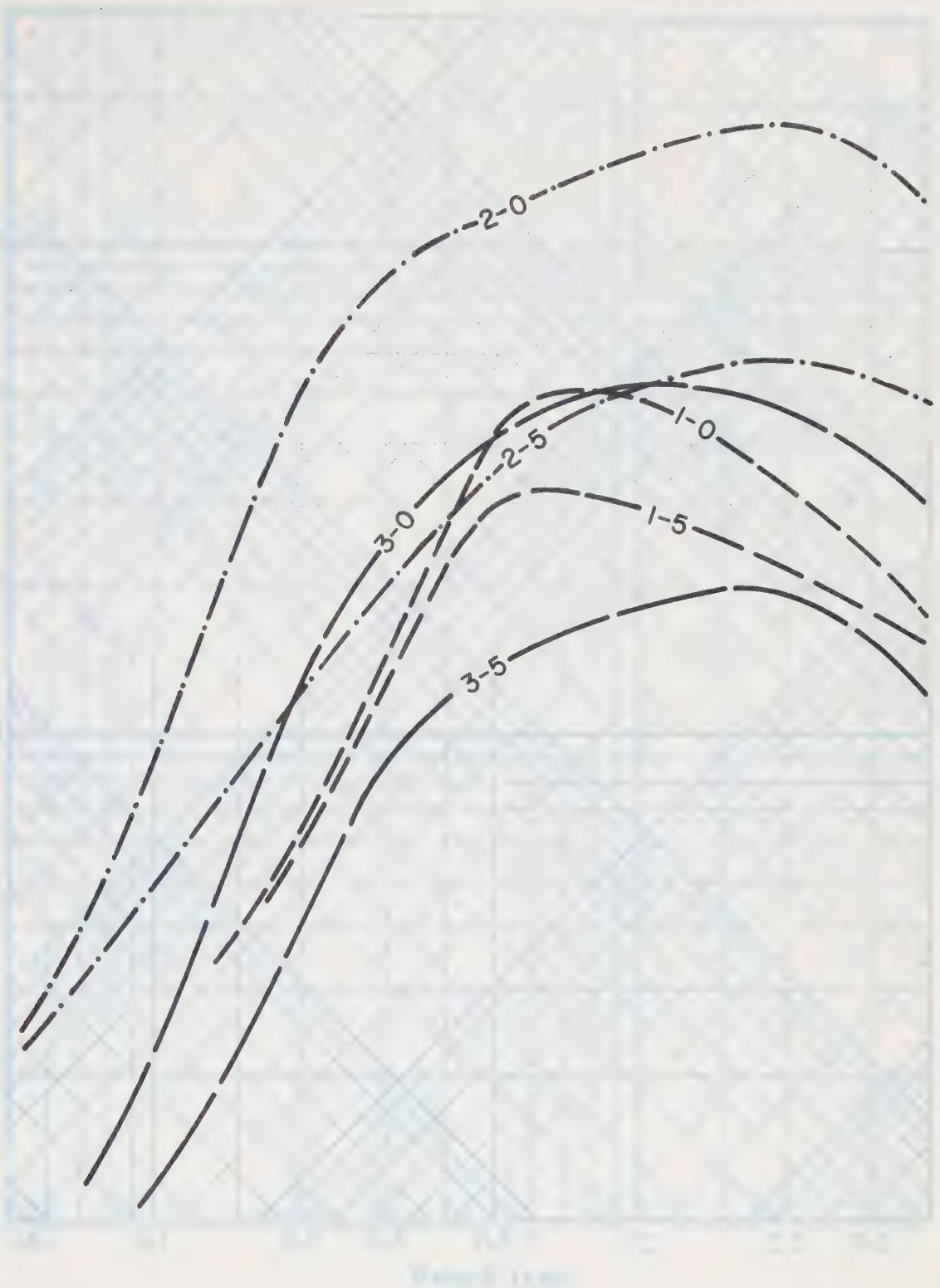
Determination of the applicable spectra cannot be made for undeveloped areas along the bluffs south of Pacific Coast Highway because substantial modification of existing conditions will occur during development. Shaking parameters should be applied by the engineering geologist and soils engineer as follows:

<u>Zone</u>	<u>Soil or Rock Condition</u>
IV	Terrace deposits, San Pedro and Palos Verdes Sandstones
IVb	Miocene bedrock
IVs	Dune sand, compacted fill

The spectra are significantly greater than the requirements of the Uniform Building Code for multistory steel-frame buildings (curve "UBC" on Figure 42), but are comparable to the design spectra now under consideration (Los Angeles, 1972) by the City of Los Angeles for incorporation into their building code.

TABLE 12
AMPLIFICATION PARAMETERS FOR LOCAL VARIATIONS

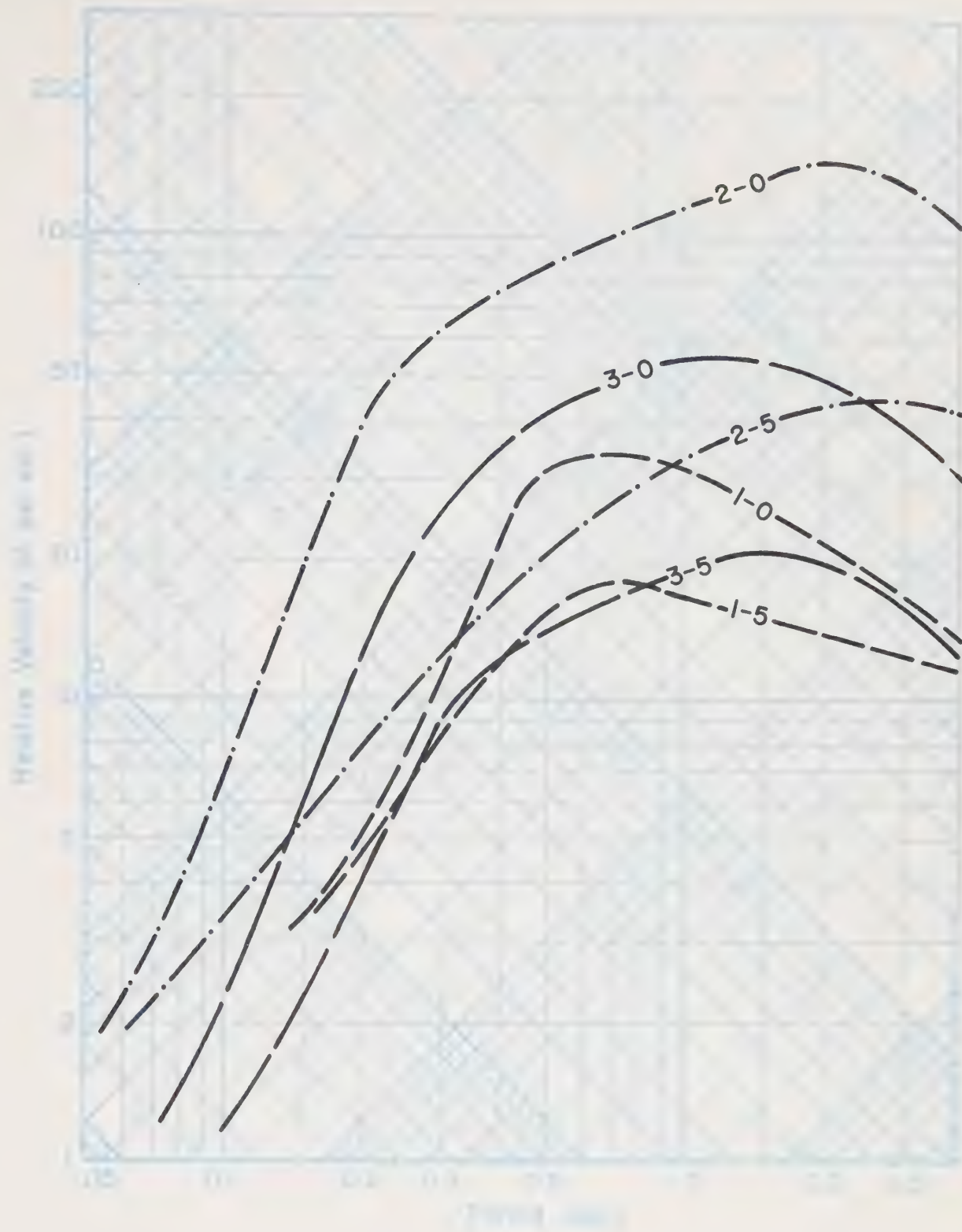
Rock or Soil Characteristic	Factor for Short Periods	Transition (Seconds)	Factor for Long Periods
Firm ground	10	1.0	5
Dune sand (less than 140')	12	1.0	5
Dune sand (greater than 140')	12	1.4	5
Tertrary rocks	8	0.3	3



Zone I

Figure 32.

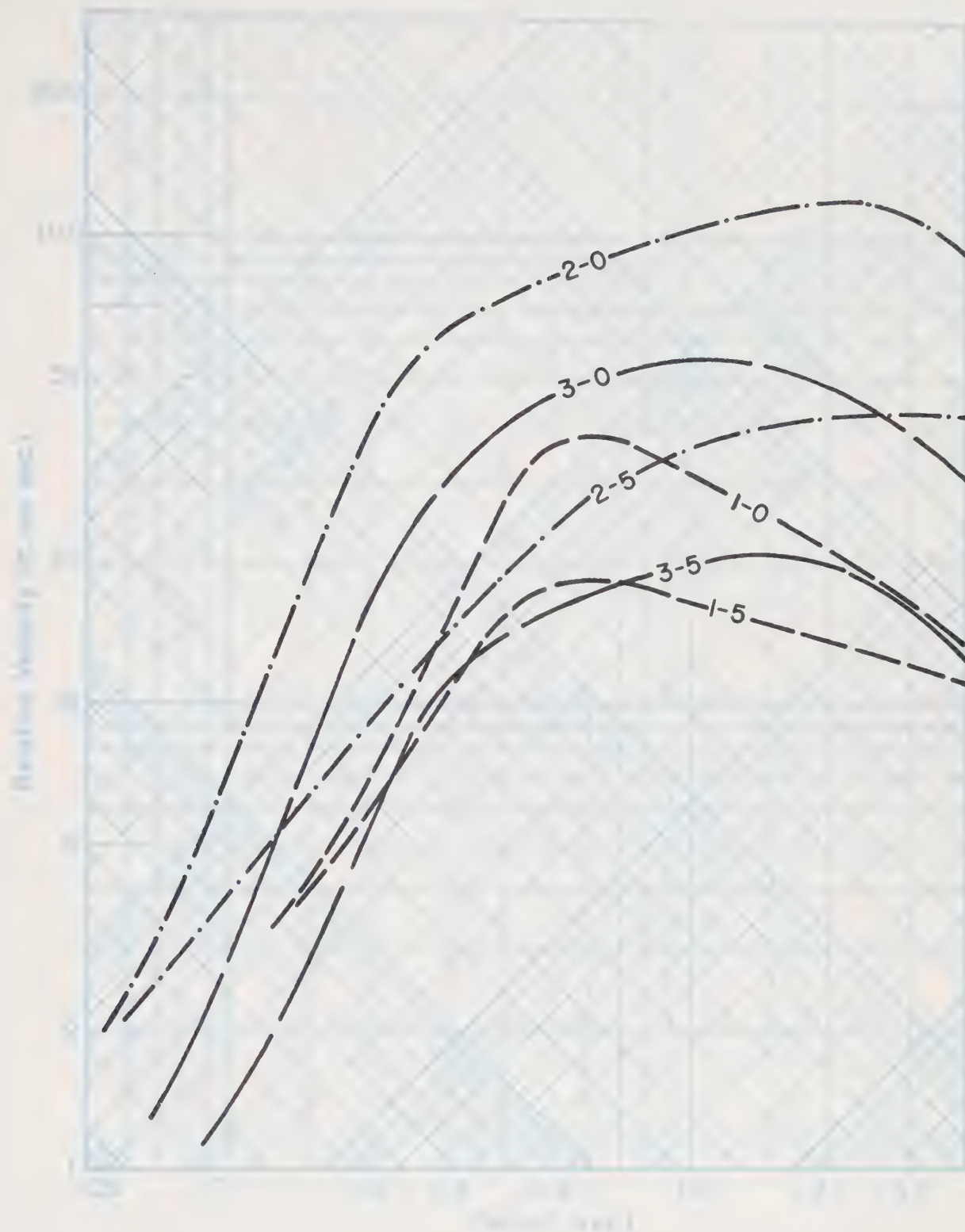
- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone II

Figure 33.

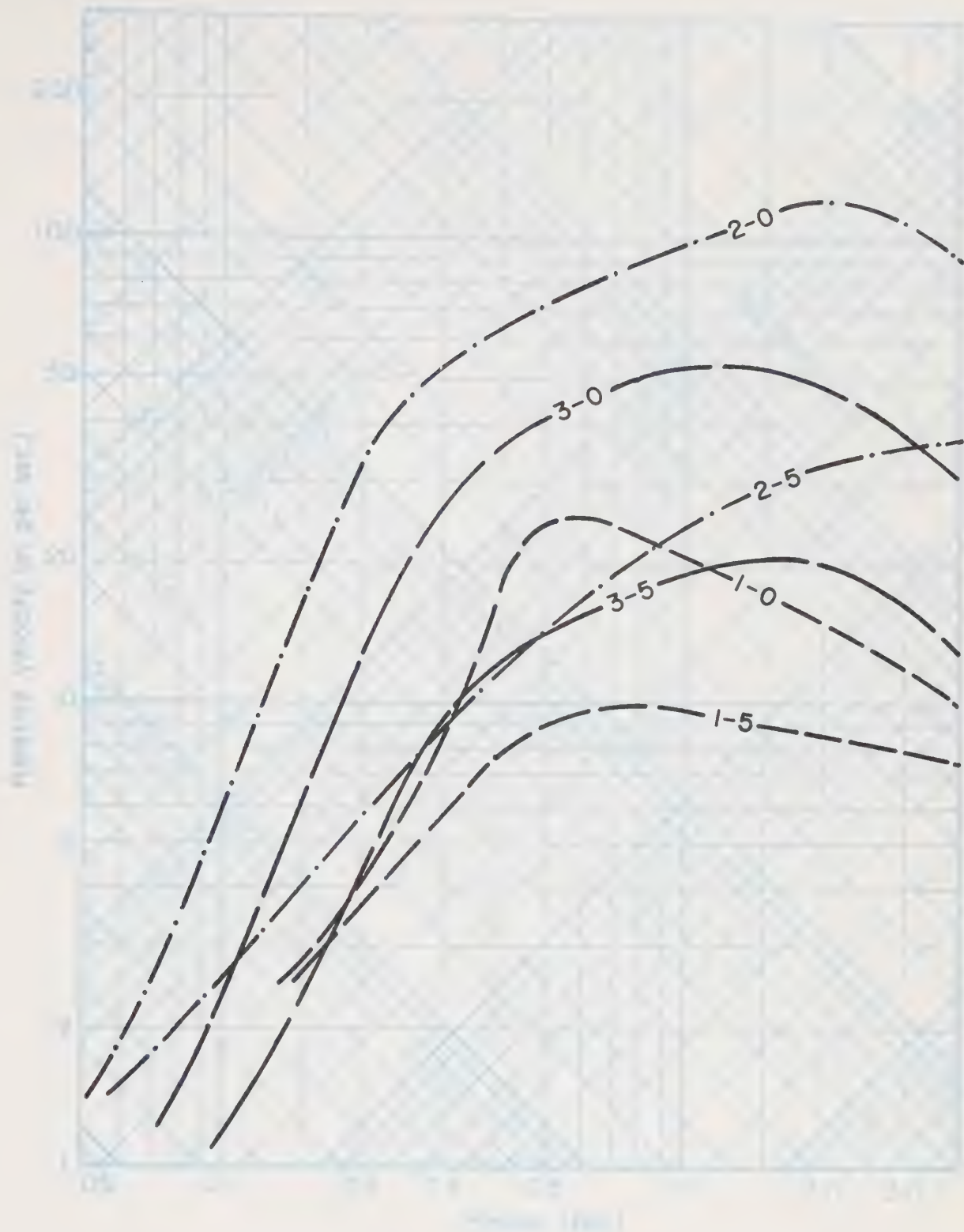
- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone IIs

Figure 34.

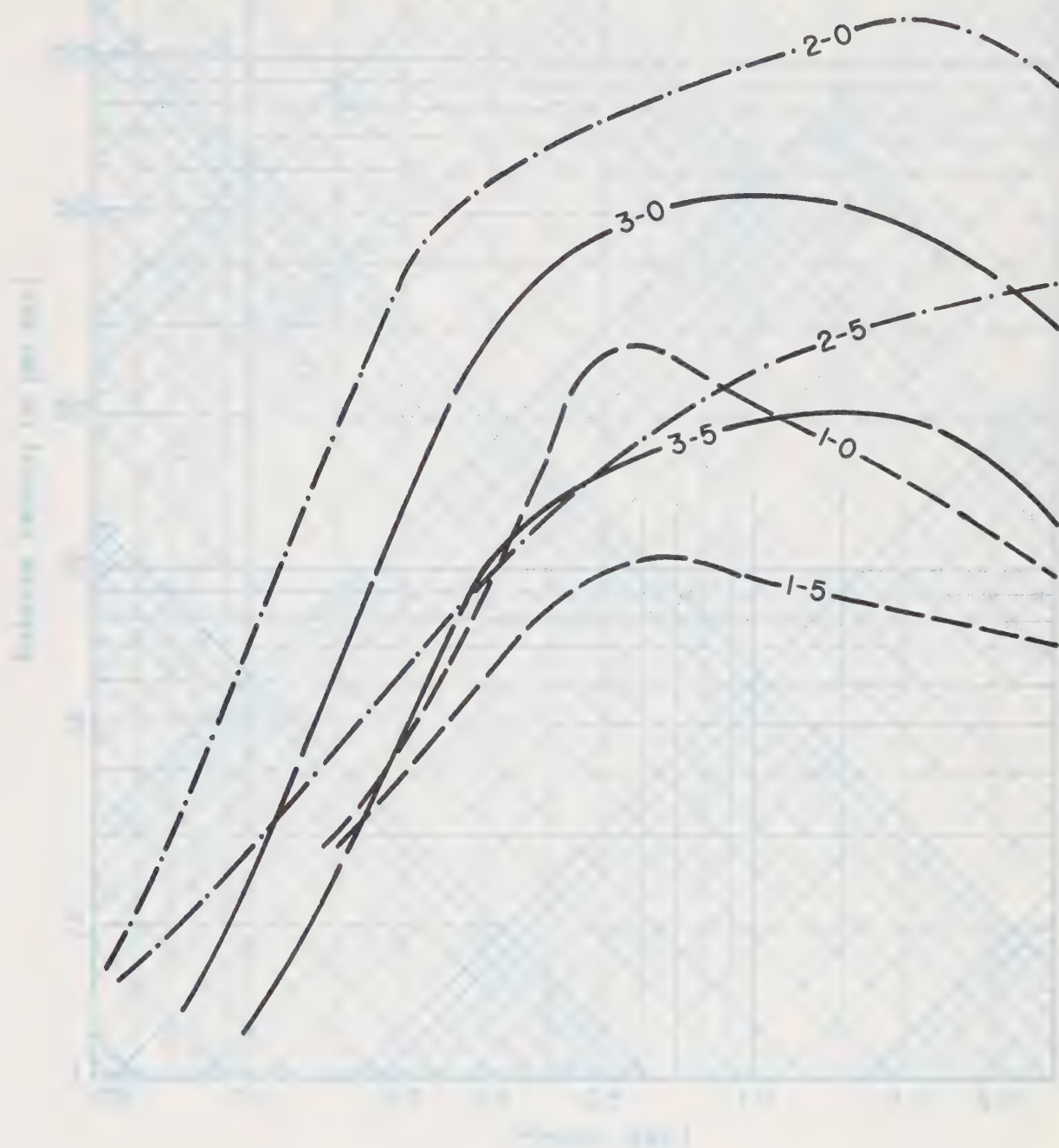
- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone III

Figure 35.

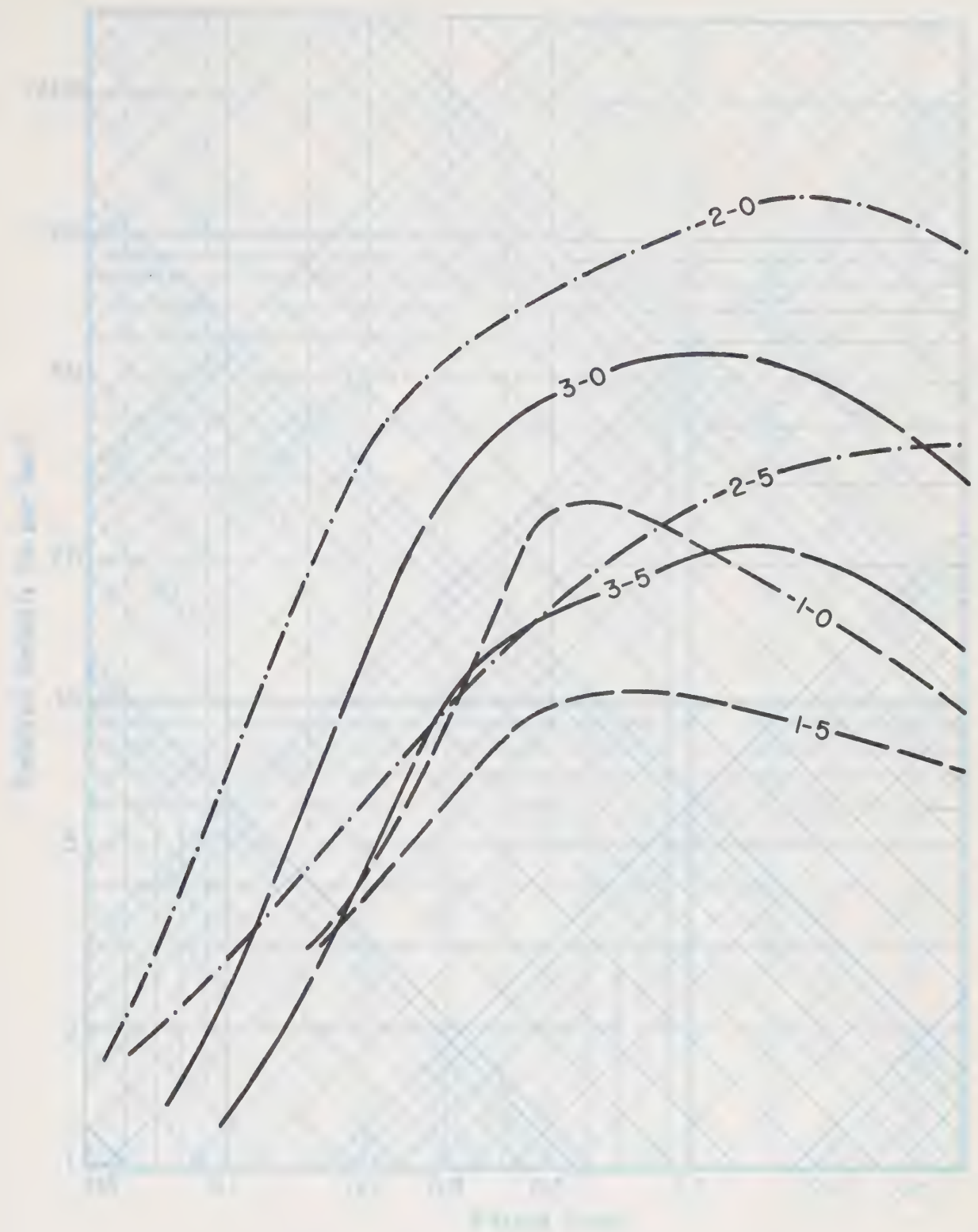
- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone IIIs

Figure 36.

- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone IIIIs

Figure 37.

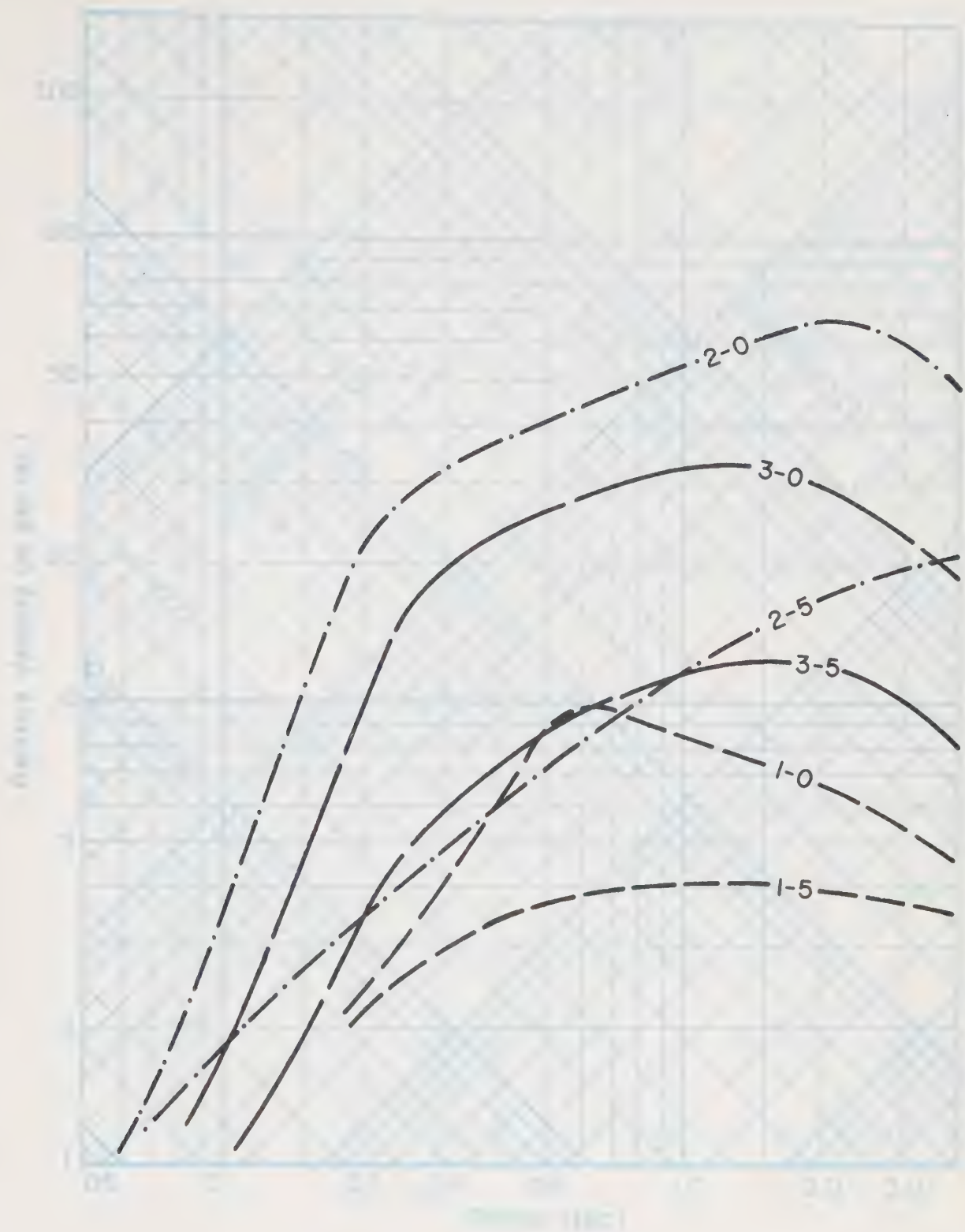
- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone IV

Figure 38.

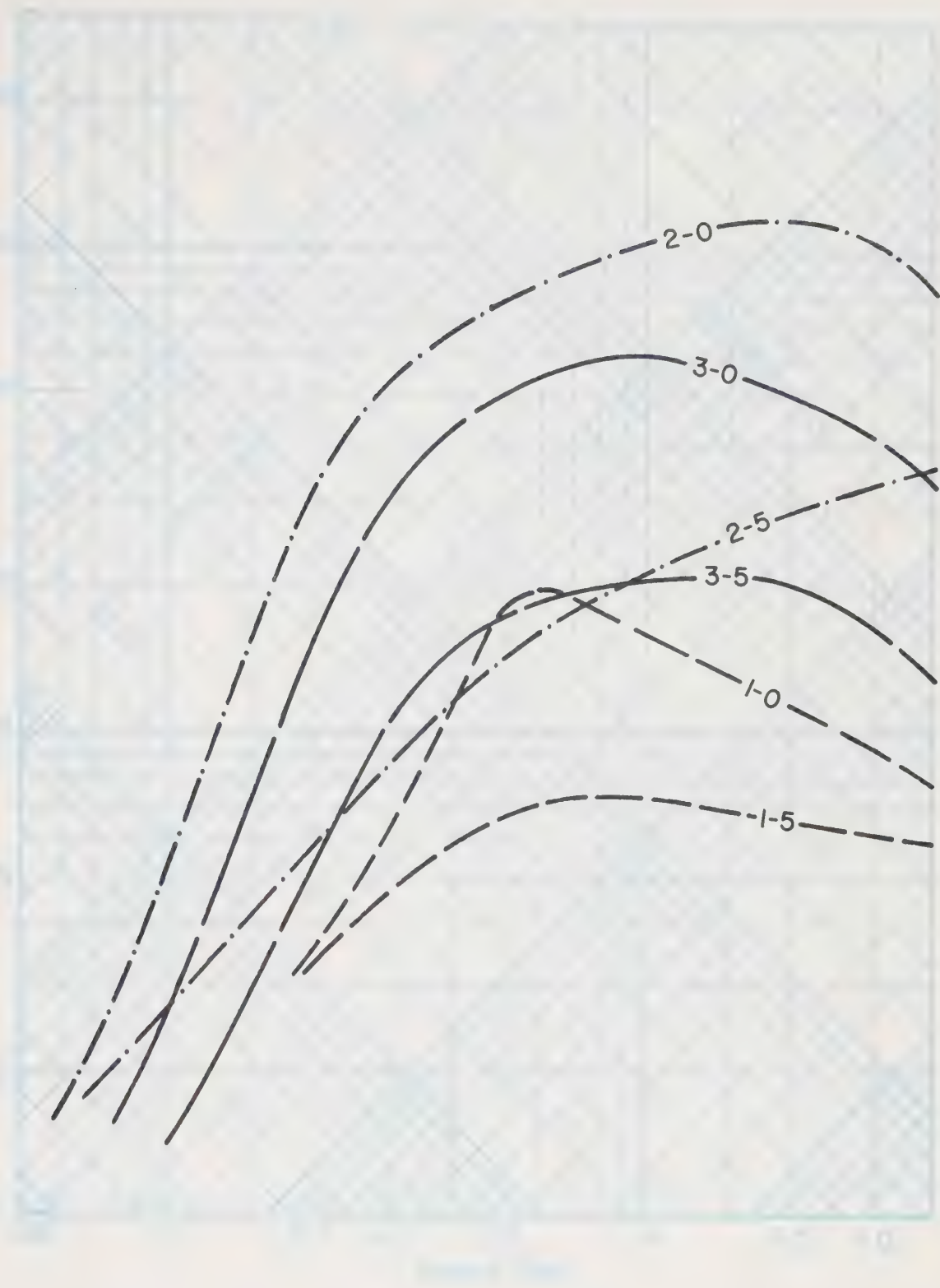
- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone IVb

Figure 39.

- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone IVs

Figure 40.

- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping



Zone IVts

Figure 41.

- 1-0 Magnitude 5.6, Newport-Inglewood fault zone, 0% critical damping
- 1-5 Magnitude 5.6, Newport-Inglewood fault zone, 5% critical damping
- 2-0 Magnitude 6.5, Newport-Inglewood fault zone, 0% critical damping
- 2-5 Magnitude 6.5, Newport-Inglewood fault zone, 5% critical damping
- 3-0 Magnitude 8.5, San Andreas fault zone, 0% critical damping
- 3-5 Magnitude 8.5, San Andreas fault zone, 5% critical damping

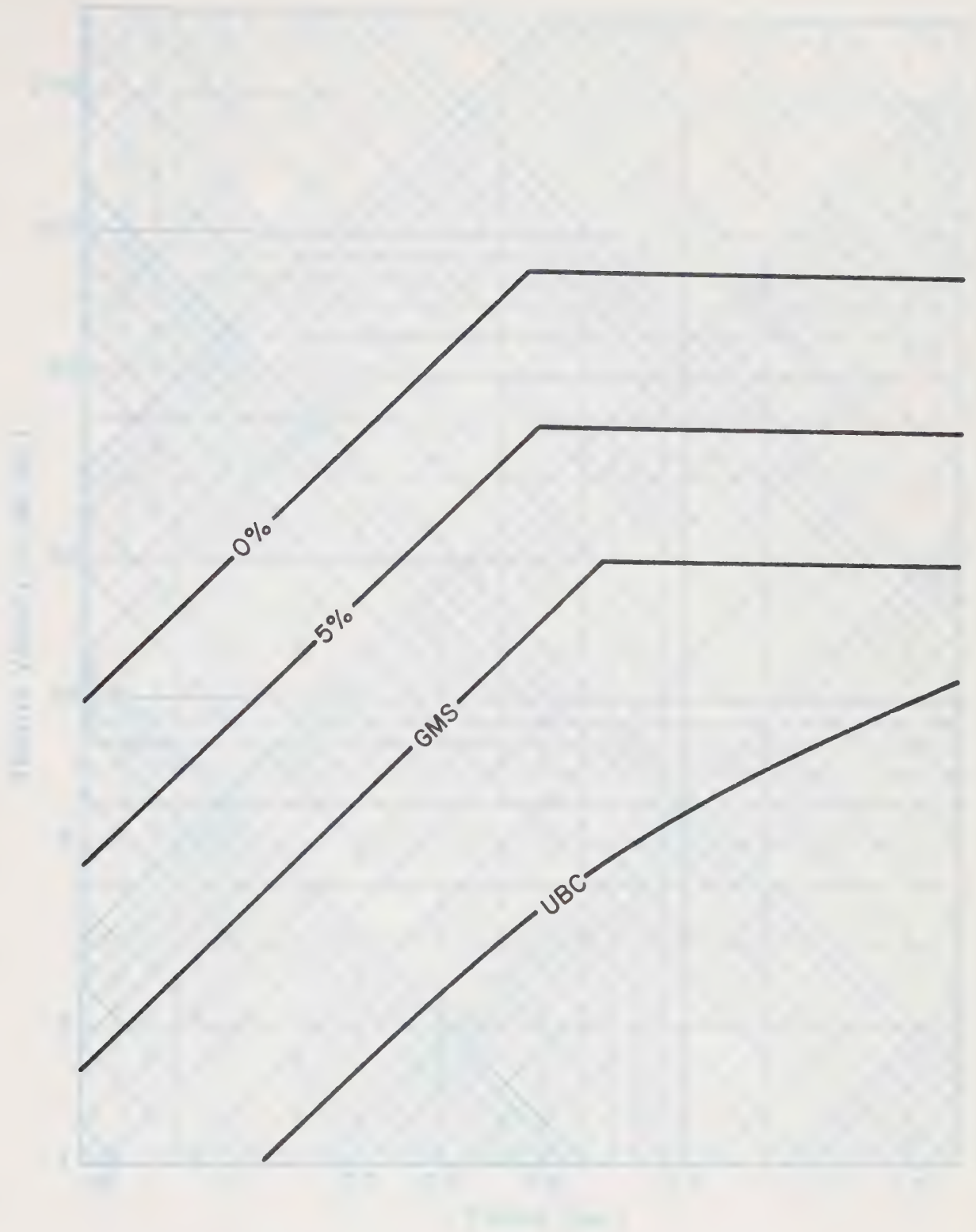


Figure 42. Design spectra for 0% and 5% critical damping and ground motion spectra (GMS) now under consideration by the City of Los Angeles for incorporation into their building code. The Uniform Building Code earthquake requirements for multistory steel-frame buildings expressed as a design spectrum (Housner, 1970) is curve UBC.

E. REGIONAL EFFECTS OF EXPECTED EARTHQUAKES

1. General Statement

The preparation of a disaster plan for expected earthquakes requires the anticipation of events not only within the city itself but also in areas surrounding the city. The effects on regional utility and transportation systems and the degree to which the city could expect aid from nearby cities are only a few examples of problems that should be considered.

The following two sections discuss effects that should be expected as the result of significant earthquakes on the Newport-Inglewood and on the San Andreas fault zones. It should be emphasized that these effects should be considered as potential occurrences in that they are based on general experience rather than specific studies.

2. Earthquakes on the Newport-Inglewood Fault Zone

The maximum shaking for earthquakes from this source would be centered about 2 miles to the northeast of the northernmost part of Torrance. Very little disruptive damage should be expected from the magnitude 5.2 event, but the larger events could result in substantial disruption of utilities and communications. Moderate damage with some temporary closings of the Harbor and San Diego Freeways should be expected as the result of the magnitude 5.6 event. The magnitude 6.5 event could result in the closing of either or both freeways for a matter of weeks, with reduced capacities for a period of possibly several months. Significant disruption of utilities would probably be limited to the magnitude 6.5 event. Breaks should be expected in electrical distribution lines, and probably also in arterial gas and water lines serving Torrance from the northeast or east.

For each of the three events, damage should be expected to be at least as great, and probably greater in adjacent areas to the northeast

including much of south-central and west Los Angeles. These areas contain more of the older buildings that are generally more susceptible to damage. Assistance in repairing and restoring essential services might come from communities in Orange County or the east and northeast Los Angeles area. However, adjacent communities will have their own problems, and should not be counted on for assistance.

3. Earthquake on the San Andreas Fault Zone

The expected "great" earthquake on the San Andreas fault zone between San Bernardino and Parkfield will be a regional disaster in Southern California with damage extending over a much larger area than can be expected from earthquakes on the Newport-Inglewood fault zone. Damage in Torrance will be relatively minor in comparison to that which will probably occur in the cities and counties to the northeast and north. Lengthy disruptions or significant reductions in services should be expected. The California and Owens River Aqueducts will probably be cut for a matter of months. The Colorado River Aqueduct may also be damaged, but probably to a lesser extent. Southern California should expect to be limited to local sources for a matter of months. Disruptions of gas and electrical arteries may also occur, but these could probably be repaired in a matter of a few days.

Damage to road and rail transportation will be severe. Interstate 5 and 15 will probably be cut by fault rupture, and both these and other freeways to the north and east will probably be closed by damage to bridges and overpasses. Road and rail routes to the south and southeast are the only ones that should be counted on during the first few days or even weeks after the earthquake.

IV. SECONDARY HAZARDS

The principal secondary hazards that result from earthquakes are tsunamis, or seismic sea waves, and several types of earth failures. The latter range from small cracks that may occur as the result of the differential response of juxtaposed materials having different seismic characteristics (e. g. compacted fill and bedrock) to large-scale failures resulting from landsliding, settlement, or liquefaction. These major secondary hazards are discussed in the next four sections.

1. Landslide

Earthquakes and landslides are sometimes related in that landslides often occur during strong earthquakes. However, the relationship should not be thought of as a direct cause and effect, but rather that the earthquake triggers the landslide. Whether the slide is merely the down-slope movement of loose rock and soil on a hillside, the slippage of a hillside fill, or the movement of a deep-seated block glide, the earthquake acts to trigger an existing, potentially unstable condition.

This hazard can be minimized by utilizing engineering geologic and soils engineering supervision in development of the hillside areas in the southern part of the City. Evaluation of specific sites requires geologic and engineering data normally available only during the course of a detailed investigation of the site. As a result, evaluation of specific areas is beyond the scope of this investigation. However, the shaking parameters developed herein can be used by the soils engineer in evaluating the stability of specific sites as they are developed.

2. Settlement

Settlement may occur in underconsolidated soils during earthquake shaking as the result of a more efficient rearrangement of the individual grains. Again, the earthquake must be considered a triggering mechanism

acting on an already unstable condition, rather than the actual cause. Settlements of sufficient magnitude to cause significant structural damage are normally associated with recent alluvial sands or poorly compacted fills. No areas of this type where development appeared likely were identified during this investigation.

3. Liquifaction

Liquifaction is a further complication on settlement, and occurs when water is forced out of the pores in the soil as it "settles". This excess water momentarily liquifies the soil, causing an almost complete loss of strength in the liquified layer. If this layer is at the surface, its effect is much like that of quicksand on any structure located on it. If the liquified layer is in the subsurface, the material above it may slide laterally depending on the confinement of the unstable mass.

Liquifaction normally occurs in areas with shallow groundwater, generally less than 30 feet. Since the water table is below this depth in almost all of Torrance, liquifaction is not considered a general problem. However, it may be a potential problem in local areas along the bluffs south of Pacific Coast Highway where springs or perched water conditions may cause periods of high saturation in fills or loose sediments. This problem can best be minimized by proper engineering geologic and soils engineering supervision during construction.

4. Tsunami

The most common method by which a tsunami, commonly called a "tidal wave", may be generated is by fault movement under the ocean. Any hazard to Torrance then would occur as the result of faulting under the Pacific rather than as the result of movement long or shaking from one of the faults already discussed. While there are many faults capable

of generating such waves, they have been rare in Santa Monica Bay. Also, the topography is abrupt along the Torrance shoreline (40 feet or more), and the risk to occupied structures is considered insignificant.

ROLE OF THE CITY OF TORRANCE IN IMPLEMENTING A PLAN OF SEISMIC SAFETY

1. New Construction

Two basic concepts should be considered in the upgrading and enforcing of building codes involving seismic risk. First, the basic concern of the City is the safety of its citizens. To implement this concern, it should adopt and enforce a code for the design of new construction that will protect them, at an acceptable level of risk, against death or serious injury. That is, a structure may be rendered completely useless due to damage during an earthquake; but if it does not collapse and no one is killed or seriously injured, then the structure has performed adequately from the standpoint of public safety. The owner of the structure may choose to upgrade the design to provide additional protection against damage, but this should not be imposed on him as it may not be economically feasible.

The second basic concept is that certain critical facilities such as hospitals, fire and police stations, and communications centers will be required to function in the hours immediately following a damaging earthquake. The level of protection desirable for a home or an office building may not be adequate for the structures in which these necessary services are housed. The following three levels of risk were discussed in a previous section:

Use	Magnitude of Design Earthquakes	
	Newport-Inglewood fault zone	San Andreas fault zone
Limited occupancy	5.2	8.5?
Normal occupancy	5.6	8.5
Critical facilities	6.5	8.5

2. Existing Structures

All high-risk structures should be identified, and strengthened or modified wherever possible. There are many economic and social problems involved in a program of this type, but several alternatives are available. If it is not economically feasible to provide an adequate level of protection by strengthening a structure, a lower level of occupancy may be desirable. If many high-risk structures are located in one area, redevelopment may be a solution.

A program of this type may require several years. The earliest attention should be given to critical facilities. Their ability to function immediately after an earthquake will affect all of the citizens of the City, and they should receive the highest priority.

3. Disaster Plan

A disaster plan should be developed by the City taking into account both the effects of an earthquake within the City and effects that can be expected in surrounding areas. The latter is discussed in detail in Section III E. The most important point is that it should be expected that damage will probably be more severe in communities to the north and east of Torrance than in the City itself. Also, major arteries for transportation, communication, and utilities leading to the City may be severed for days or weeks. The plan should, therefore, be based on

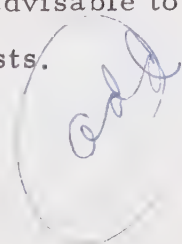
the continued functioning of necessary services within the City rather than an evacuation to nearby communities. On the contrary, Torrance may be asked to accommodate earthquake victims from outside the City. The extent of this possibility should be determined on an area-wide basis by the City and/or County of Los Angeles.

4. Continued Upgrading of Technical Data Base

The City should encourage the continued upgrading of the technical data base. Two accelerographs have recently been installed in the Golden West Towers, and their installation in new major structures should be promoted. The accelerographs required by the City of Los Angeles have been a major source of the data needed to analyze the ground motion of earthquakes and the response of structures, and therefrom to develop criteria for the design of structures capable of withstanding large earthquakes. Detailed site investigations for major structures should be encouraged. The results would be applicable not only to the structures themselves, but also to the refining of the spectra developed herein for the several zones within the City.

Engineering geologic and soils engineering supervision of hillside development should be continued particularly in the area of the Palos Verdes fault zone. Evaluation of individual sites should utilize the data on expected shaking developed herein and the data available as a result of detailed geologic and soils investigations of the site.

Water injection has been undertaken on a large scale in the Torrance oil field only recently (Appendix D), and it is too early to establish any firm relationship between the injection and micro-seismic activity. However, if future experience indicates a possible relationship, it may be advisable to monitor the activity to determine if a potential hazard exists.



APPENDIX A
TERMINOLOGY AND CONCEPTS

A. GENERAL CHARACTERISTICS OF EARTHQUAKES

1. The Source of Earthquakes

Earth scientists are generally agreed that earthquakes originate as the result of an abrupt break or movement of the rock in the relatively brittle crust of the earth. The earthquake is the effect of the shock waves generated by the break, much the same as sound waves (a noise) are generated by breaking a brittle stick. If the area of the break is small and limited to the deeper part of the crust, the resulting earthquake will be small. However, if the break is large and extends to the surface, then the break can result in a major earthquake.

These breaks in the earth's crust are called faults. In California, faults are extremely common, and vary from the small breaks of an inch or less that can be seen in almost any road-cut, to the larger faults such as the San Andreas on which movement over many millions of years has amounted to hundreds of miles. In addition to the size of faults, their "age" is also important. Many large faults have not moved for millions of years; they are considered "dead" or no longer active. They were probably the source of great earthquakes millions of years ago, but are not considered dangerous today.

Since faults vary as to the likelihood of their being the source of an earthquake, considerable effort has, and is continuing to be expended by geologists and seismologists to determine and delineate the faults likely to generate significant earthquakes. These faults are classified generally as follows:

- (1) An historically active fault is one which is known to have slipped during historical time, or one which is associated with an alignment of earthquake epicenters. In California this "historical time" span is limited to approximately 150 years.

- (2) An active fault is one that has moved in the recent geologic past, and that can be expected to move again in the foreseeable future. The "recent geologic past" is generally interpreted to include recent geologic time; a period of approximately 10,000 years. However, a precise definition of "active fault", such as is needed where the term is included in legal documents, is still a matter of considerable debate.
- (3) A potentially active fault is one that lacks the criteria to be classified as active, but which must be considered suspect because of offset of Quaternary (up to approximately 2 million years) sediments or the presence of scattered earthquake epicenters. This classification may be applied as much due to lack of definitive data as to the presence of data that definitely precludes recent movement.

2. Man-Induced Earthquakes

Until recently most earth scientists would not have accepted the idea that man could induce or "trigger" earthquakes. However, events near the Rocky Mountain Arsenal near Denver and detailed studies of events in the Rangely oil field in western Colorado indicate that man can induce earthquakes by pumping fluids into the ground under pressure. The theory is that the increased fluid pressure reduces friction, and allows accumulated stress to dissipate as small earthquakes.

Research on this problem by the U. S. Geological Survey is continuing, as this concept offers some hope that large, damaging earthquakes can be avoided by inducing a larger number of smaller earthquakes.

3. Describing an Earthquake

Several terms are used to describe the location, "size", and effects of an earthquake. A clear understanding of the meaning of these terms

and their limitations is essential to an understanding of the results of the investigation.

The location of an earthquake is generally given as the epicenter of the earthquake. This is a point on the earth's surface vertically above the hypocenter or focus of the quake. The latter is the point from which the shock waves first emanate. However, as discussed above earthquakes originate from faults. These are surfaces not points, so the hypocenter is only one point on the surface (or volume) that is the source of the earthquake.

Magnitude describes the size of the earthquake itself. Technically it is defined as the log of the maximum amplitude as recorded on a standard seismograph at 100 kilometers (62 miles) from the epicenter. The most important part of this definition is that it is a log scale; that is, an increase of 1 on the magnitude scale (e.g. magnitude 5.0 to 6.0) represents an increase of 10 in the amplitude of the recorded wave. It should also be noted that the magnitude of an earthquake is determined at a considerable distance from the center of the earthquake, and that it is based on ground displacement rather than ground acceleration.

Intensity describes the degree of shaking in terms of the damage at a particular location. The scale used today is the Modified Mercalli Scale, and is composed of 12 categories (I to XII) of damage as described in Table A-1. The Roman numerals are used to emphasize that the units in the scale are discrete categories rather than a continuous numerical sequence as is the magnitude scale. It is important to remember that intensity is a very general description of the effects of an earthquake, and depends not only on the size of the quake and the distance to its center but also on the quality of the construction that has been damaged and the nature of local ground conditions.

excitement, and some persons run outdoors.

Persons move unsteadily. Trees and bushes shake slightly to moderately. Liquids are set in strong motion. Small bells in churches and schools ring. Poorly built buildings may be damaged. Plaster falls in small amounts. Other plaster cracks somewhat. Many dishes and glasses, and a few windows, break. Knick-knacks, books and pictures fall. Furniture overturns in many instances. Heavy furnishings move.

VII Frightens everyone. General alarm, and everyone runs outdoors.

People find it difficult to stand. Persons driving cars notice shaking. Trees and bushes shake moderately to strongly. Waves form on ponds, lakes and streams. Water is muddied. Gravel or sand stream banks cave in. Large church bells ring. Suspended objects quiver. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Plaster and some stucco fall. Many windows and some furniture break. Loosened brickwork and tiles shake down. Weak chimneys break at the roofline. Cornices fall from towers and high buildings. Bricks and stones are dislodged. Heavy furniture overturns. Concrete irrigation ditches are considerably damaged.

VIII General fright, and alarm approaches panic. Persons driving cars are disturbed. Trees shake strongly, and branches and trunks break off (especially palm trees). Sand and mud erupts in small amounts. Flow of springs and wells is temporarily and sometimes permanently changed. Dry wells renew flow. Temperature of spring and well waters varies. Damage slight in brick structures built especially to withstand earthquakes; considerably in ordinary substantial buildings, with some partial collapse; heavy in some wooden houses, with some tumbling down. Panel walls break away in frame structure. Decayed pilings break off. Walls fall. Solid stone walls crack and break seriously. Wet ground and steep slopes crack to some extent. Chimneys, columns, monuments and factory stacks and towers twist and fall. Very heavy furniture moves conspicuously or overturns.

IX Panic is general.

Ground cracks conspicuously. Damage is considerable in masonry structures built especially to withstand earthquakes; great in other masonry buildings — some collapse in large part. Some wood frame houses built especially to withstand earthquakes are thrown out of plumb, others are shifted wholly off foundations. Reservoirs are seriously damaged, and underground pipes sometimes break.

X Panic is general.

Ground, especially when loose and wet, cracks up to widths of several inches; fissures up to a yard in width

run parallel to canal and stream banks. Landsliding is considerable from river banks and steep coasts. Sand and mud shifts horizontally on beaches and flat land. Water level changes in wells. Water is thrown on banks of canals, lakes, rivers, etc. Dams, dikes, embankments are seriously damaged. Well-built wooden structures and bridges are severely damaged, and some collapse. Damgerous cracks develop in excellent brick walls. Most masonry and frame structure, and their foundations, are destroyed. Railroad rails bend slightly. Pipe lines buried in earth tear apart or are crushed endwise. Open cracks and broad wavy folds open in cement pavements and asphalt road surfaces.

XI Panic is general.

Disturbances in ground are many and widespread, varying with the ground material. Broad fissures, earth slumps, and land slips develop in soft, wet ground. Water charged with sand and mud is ejected in large amounts. Sea waves of significant magnitude may develop. Damage is severe to wood frame structures, especially near shock

centers; great to dams, dikes and embankments, even at long distances. Few if any masonry structures remain standing. Supporting piers or pillars of large, well-built bridges are wrecked. Wooden bridges that "give" are less affected. Railroad rails bend greatly, and some thrust endwise. Pipe lines buried in earth are put completely out of service.

XII Panic is general.

Damage is total, and practically all works of construction are damaged greatly or destroyed. Disturbances in the ground are great and varied, and numerous shearing cracks develop. Landslides, rock falls, and slumps in river banks are numerous and extensive. Large rock masses are wrenched loose and torn off. Fault slips develop in firm rock, and horizontal and vertical offset displacements are notable. Water channels, both surface and underground, are disturbed and modified greatly. Lakes are dammed, new waterfalls are produced, rivers are deflected, etc. Surface waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

4. Occurrence and Recurrence of Earthquakes

Earthquakes have had in the past a certain occurrence in space and time. These occurrences may or may not set certain patterns that can form the basis for predicting their occurrence in the future. When such occurrences are analyzed in time, certain characteristics may statistically recur at definite intervals. If it can be shown that a particular magnitude earthquake recurs on a fault on the average of a certain number of years, this number can be said to be the recurrence interval for that magnitude. Or, if the interval of time is set (e. g. a 100-year period), then earthquakes of a particular magnitude will recur a certain number of times in the specified period.

In California, as in most large areas, small earthquakes occur much more often than large earthquakes. Also, there is a fairly definite pattern in that the log (base 10) of the number of events of a particular magnitude that have occurred in the past is approximately proportional to the magnitude of those events. This relationship appears to apply to larger areas such as California and western Nevada, some smaller areas such as the Los Angeles Basin, and to some faults such as the Newport-Inglewood. However, this relationship does not apply to all faults, and it should be applied to small areas, such as cities or individual sites, with great care.

B. ENGINEERING CHARACTERISTICS OF EARTHQUAKES

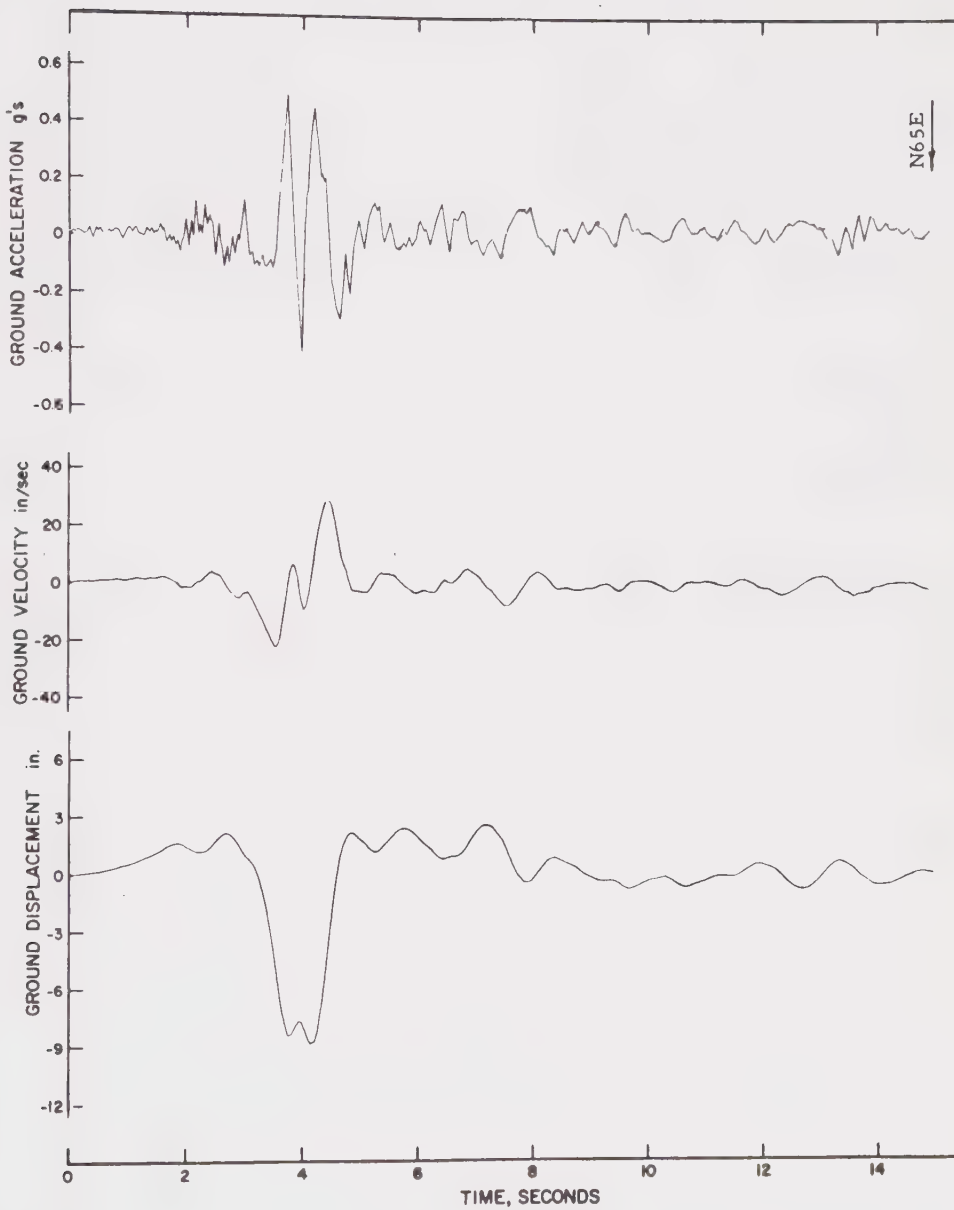
The data of seismologists and geologists are, in general, not applicable to the engineering design of earthquake-resistant structures. The seismograph, for example, is a very sensitive instrument designed to record earthquakes at great distances. A level of shaking that would be meaningful to an engineer in designing a building would put most seismographs completely off-scale.

As a result, it has been necessary to design and install special instruments to record the strong motions of earthquakes that are of interest to the engineer in the design of earthquake-resistant structures. The first such instruments, principally accelerographs and seismoscopes, were installed by the U.S. Coast and Geodetic Survey in the late 1920's, and the 1933 Long Beach earthquake was the first real test of this system. The motions were apparently stronger than expected, and the accelerograph record from Long Beach itself has never been adequately deciphered. Since that time, the instrumentation and analytical techniques have been continuously improved, and many excellent records have been obtained of the more recent strong earthquakes.

The following sections are a brief introduction to the concepts, data and application of strong-motion records. The science is relatively young, and is growing in bursts that follow the recording of a damaging earthquake.

1. Acceleration, Velocity and Displacement

The accelerograph is a short-period instrument (in contrast to the seismograph), and measures the acceleration of the ground or the structure on which it is mounted. Figure A-1 shows the ground acceleration recorded just a few hundred feet from the fault during the 1966 Parkfield earthquake. The velocity and displacement curves have been derived



Station 2 N65E Motion.

from Housner & Trifunac, 1967

Figure A-1

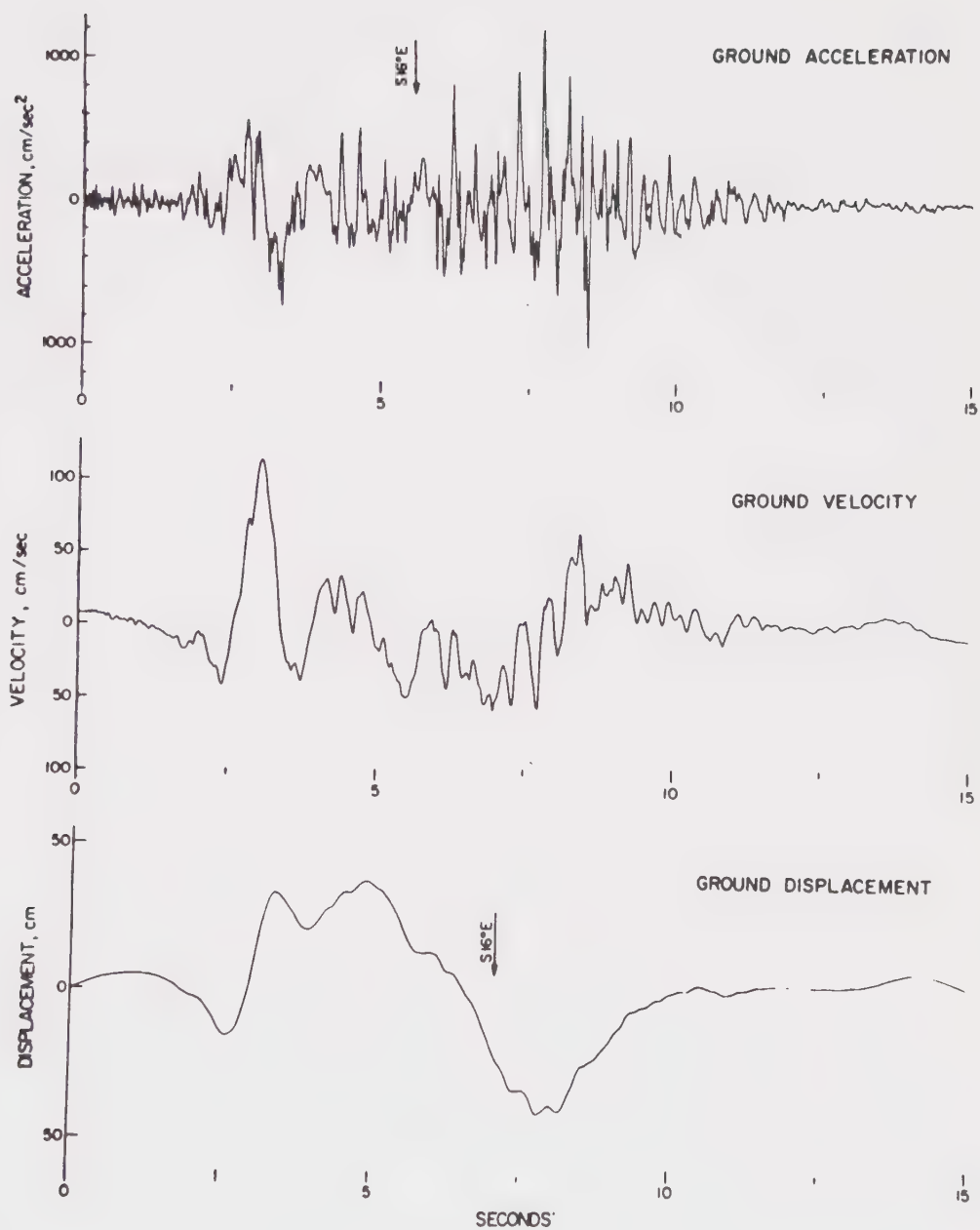
from it by integration. It is a particularly good example of the relationships of these three parameters of motion because of the relatively "clean", single-displacement pulse that corresponds to two velocity peaks and four acceleration peaks. Figure A-2 shows the more typically complex record of the San Fernando earthquake as recorded at Pacoima Dam. Neither of the two, however, are typical records in terms of accelerations recorded. The Pacoima record shows the largest acceleration recorded to date (1.25g), and the Parkfield record (0.5g) was the largest before the San Fernando earthquake.

It should also be noted that accelerographs normally record three components; two in the horizontal plane at a right angle to each other, and one vertical. Only one component is shown in each of the two examples.

Maximum acceleration is one of the basic parameters describing ground shaking, and has been the one most often requested by agencies as FHA in determining the earthquake hazard to residential structures. It is particularly important for "low-rise" construction (up to 3 to 5 stories) and other structures having natural periods in the range of 0.3 - 0.5 seconds or less.

2. Frequency Content — Fourier and Response Spectra

The frequency content of the ground motion is particularly important for the intermediate and higher structures. The problem can be compared to pushing a child in a swing. If the pushes are timed to coincide with the natural period of the swing, then each push makes the swing go higher. However, if the timing is not right, then most of the push is lost "fighting" the natural period of the swing. The situation is similar during earthquakes. Structures have certain natural periods of vibration. If the pulses of the earthquake match the natural period of the structure, even a moderate



Acceleration, velocity and displacement in the S16°E direction during the main event of the San Fernando earthquake of February 9, 1971, 06:00 (PST).

from Trifunac & Hudson, 1971

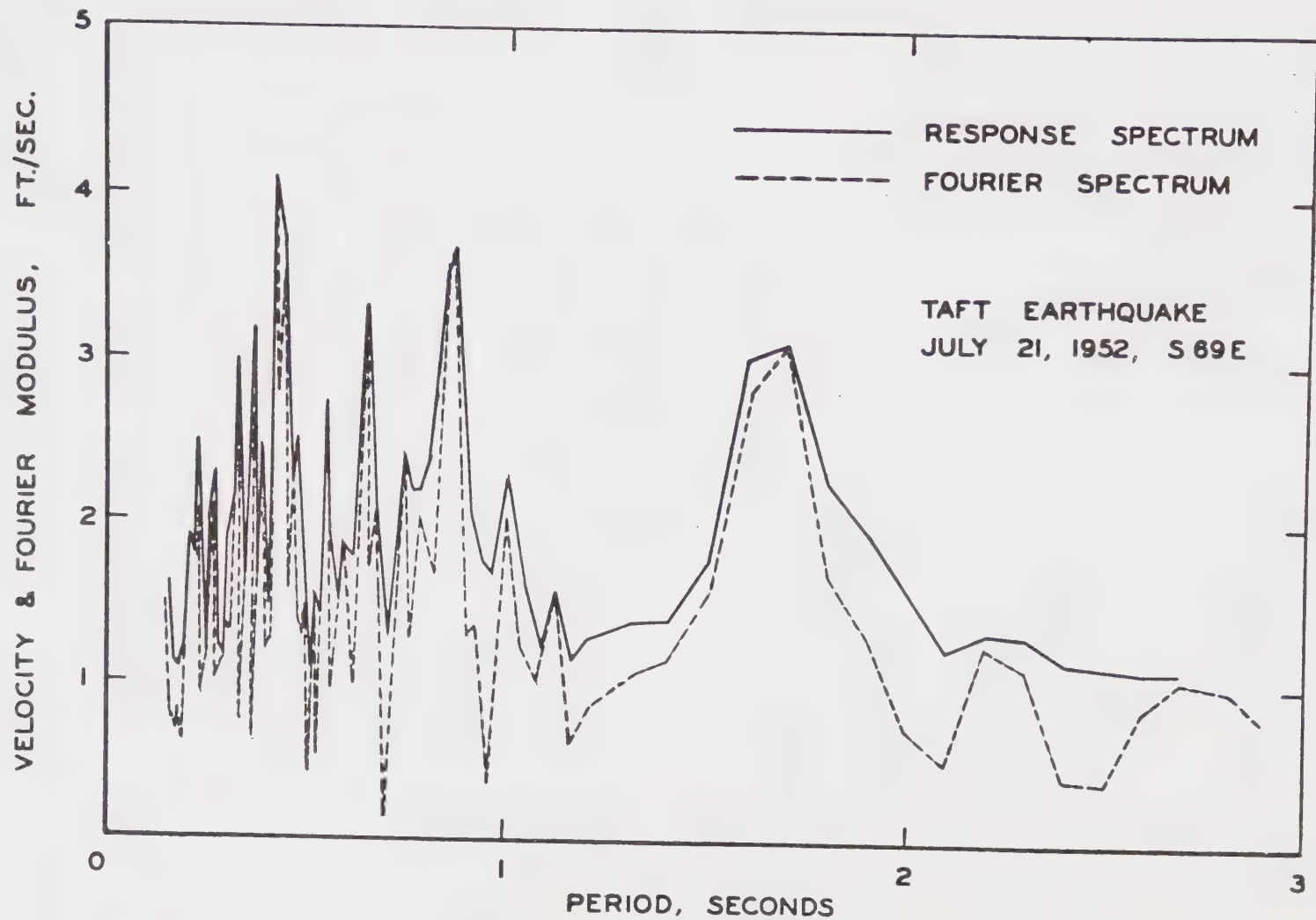
Figure A-2

earthquake can cause damaging movement. However, if the match is poor, the movement and resulting damage will be much less.

Two methods are commonly used to analyze and display the frequency content of an earthquake. A Fourier analysis is a common mathematical method of deriving the significant frequency characteristics of a time-signal such as the record of an earthquake. The results of the analysis are an amplitude term and a phase term. The amplitude is normally plotted against the period for that amplitude to give a Fourier amplitude spectrum for the range of frequencies that are of interest. Since the mathematical procedure is basically an integration of acceleration with time, the Fourier amplitude has the units of velocity.

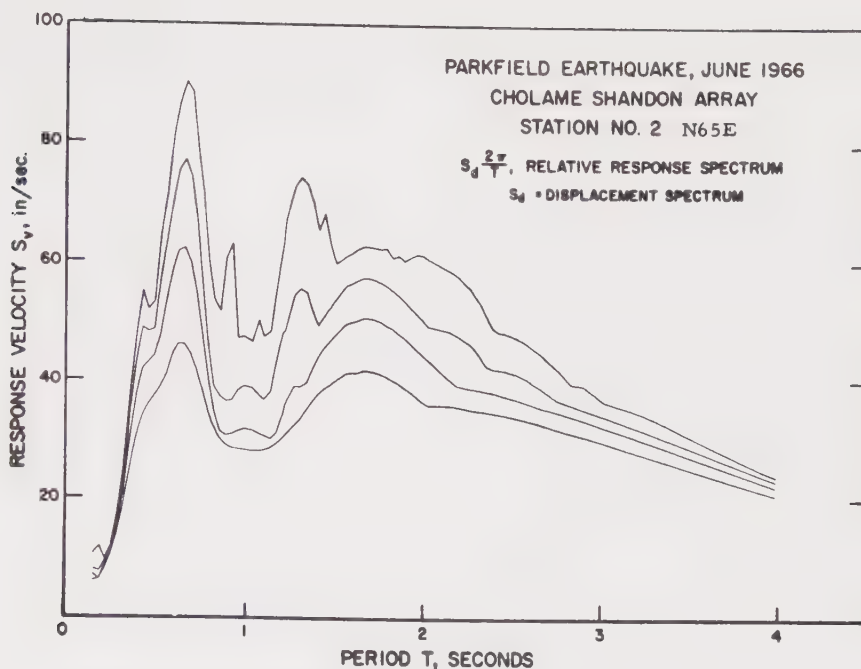
A response spectrum is derived by a similar mathematical process, but is slightly different in concept. It represents the maximum response of a series of oscillators, having particular periods and damping, when subjected to the shaking of the earthquake. The result is also expressed in terms of velocity with the particular nomenclature depending on the precise method used to derive the spectrum.

The Fourier spectrum can be generally described as the energy available to shake structures having various natural frequencies. The response spectrum gives the effect, in maximum velocity, of this available energy on simple structures having various frequencies and damping. At zero damping the two are very similar. Figure A-3 shows a plot of both the Fourier spectrum and the response spectrum with zero damping for the Taft earthquake of 1952. Figure A-4 shows the response spectrum for the Parkfield record (Figure A-1) for several levels of damping.



from Alford et al, 1964

Figure A-3



Response Spectra, Station 2-N65E. The curves are for 0, 2, 5 and 10% damping.

from Housner & Trifunac, 1967

Figure A-4

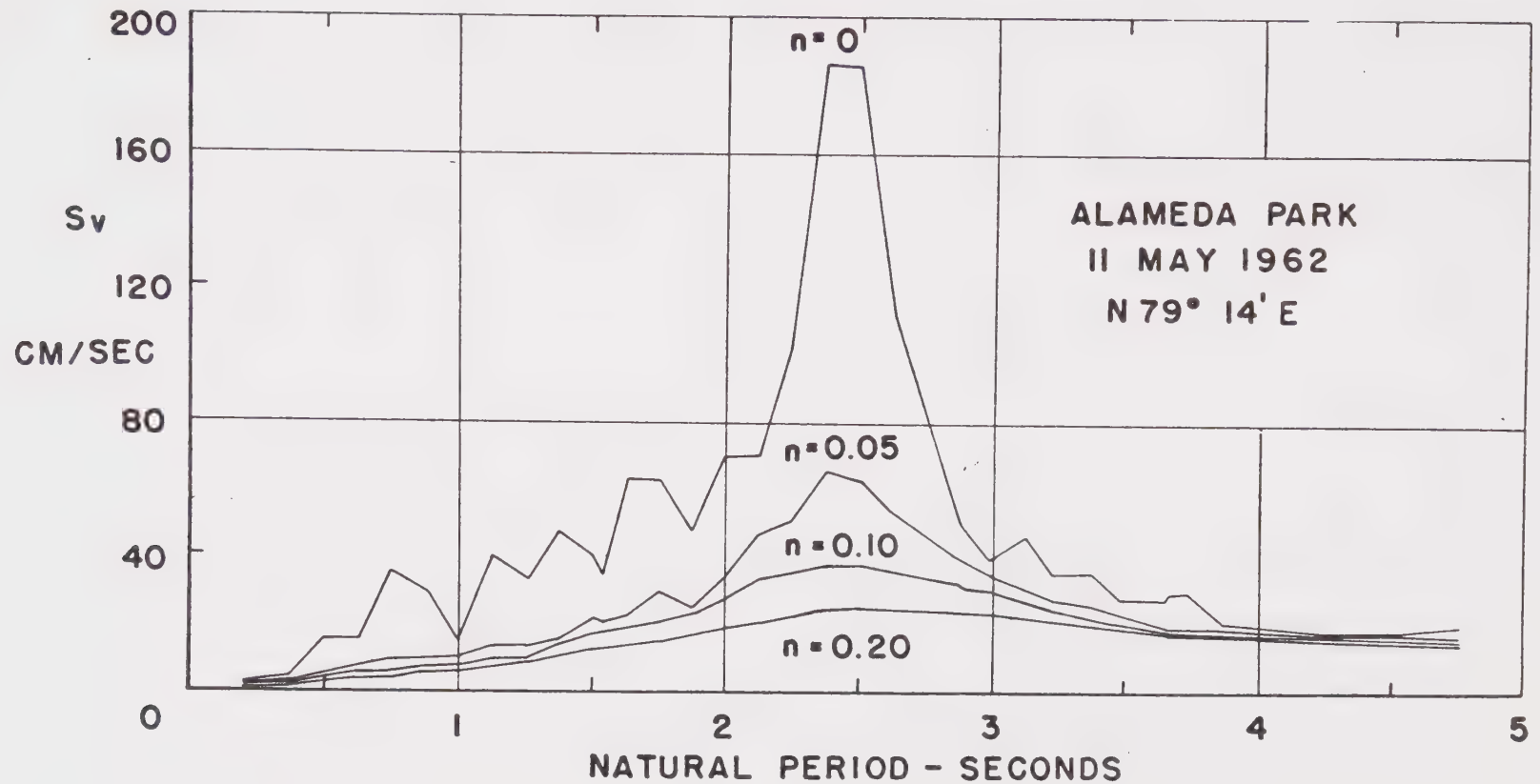
3. Near-Surface Amplification

The shock waves of an earthquake radiate outward from the source (i. e. the slipped fault) through the deeper and relatively more dense parts of the earth's crust. In this medium, the waves travel at high velocity and with relatively low amplitude. However as they approach the surface, the velocity of the medium decreases and may become quite variable if layers of different rock types are present. The overall effect is generally an amplification of the wave or of certain frequencies within the spectrum of the wave.

The most consistently applicable effect is the increase in wave amplitude that accompanies the decrease in velocity. This relationship can be compared to laws of mechanics that require the conservation of energy and momentum. In the case of earthquake waves, the energy of

velocity is transferred to energy of wave amplitude when the velocity decreases.

A second effect is the amplification of certain frequencies due to the thickness and velocity of near-surface layers of the earth. The geometry of these layers control the frequency of shaking just like the geometry of a TV antenna controls the frequency it receives best. A striking example in the very high amplification of waves of 2.5 second period (Figure A-5) by the stratification of the old lake beds on which Mexico City has been built. This concentration of the energy in a very narrow frequency range could be disastrous for structures with a matching natural period. Just like the child in the swing, they would move more and more with each successive pulse of the quake. Such pronounced amplifications are unusual, but if present, they can be extremely important.



Mexico City velocity spectrum for the Alameda Park 11 May 1962
N 79°14' E Component. (See "Mexican Earthquakes of 11 May and
19 May 1962," by P. C. Jennings, Earthquake Engineering Research
Laboratory, C.I.T.)

Figure A-5

APPENDIX B
SIGNIFICANT LOCAL EARTHQUAKES POSSIBLY
ORIGINATING ON THE
NEWPORT-INGLEWOOD ZONE,
MARCH 1933 THROUGH 1971

APPENDIX B
SIGNIFICANT LOCAL EARTHQUAKES POSSIBLY ORIGINATING ON THE NEWPORT-INGLEWOOD ZONE,
MARCH 1933 THROUGH 1971

Date	Locality	Intensity (Modified Mercalli)		Magnitude	Epicenter			
		Maximum	Torrance		N. Lat.		W. Long.	
1933 3/10	Long Beach-Newport Beach (off shore)	IX	VII	6.3	33°	36'	118°	
1933 10/02	Signal Hill (Long Beach, Los Angeles, Compton, Bell)	VI	V	5.4	33°	48'	118°	08'
1934 4/17	Newport Beach (off shore)			4.0	33°	34'	117°	59'
1934 11/16	Midway City			4.0	33°	45'	118°	0'
1935 12/25	Newport Beach (off shore)			4.5	33°	36'	118°	01'
1937 7/07	Newport Beach (off shore)			4.0	33°	34'	117°	59'
1938 5/21	Huntington Beach (off shore)			4.0	33°	37'	118°	02'
1938 8/31	Dominguez Hills			4.5	33°	48'	118°	14'
1938 12/07	Culver City-Venice			4.0	34°	00'	118°	25'
1939 12/27	Long Beach (Huntington Park, and Long Beach damaged)	VI		4.5	33°	47'	118°	12'
1940 1/13	Seal Beach			4.0	33°	47'	118°	08'
1940 2/08	Sunset Beach (off shore)			4.0	33°	42'	118°	04'
1940 2/11	Inglewood-Huntington Park			4.0	33°	59'	118°	18'
1940 7/18	Sunset Beach (off shore)			4.0	33°	42'	118°	04'
1941 10/21	Gardena (damage in west Dominguez oil field)	VII	VI	5.0	33°	49'	118°	13'
1941 10/22				3.8	33°	52'	118°	13'
1941 11/14	Torrance	VII - VIII	VII - VIII	5.5	33°	47'	118°	15'

Date	Locality	Intensity (Modified Mercalli)		Magnitude	Epicenter		
		Maximum	Torrance		N. Lat.	W. Long.	
1944 6/18	Dominguez Hills 17:03:33 PST	VI	V	4.5	33° 52'	118°	13'
1944 6/18	Dominguez Hills	VI	VI	4.4	33° 52'	118°	13'
1961 10/20	Orange County (4 larger shocks out of 8 tremors)	VI		3.9	33.7°	117.9°	
1961 10/20				4.6	33.6°	118.0°	
1961 10/20				4.2	33.7°	118.0°	
1961 10/20				4.2	33.7°	118.0°	
1961 11/20	Orange County (with 3 aftershocks)			4.0	33.7°	117.9°	
1963 2/18	Inglewood area			3.4	33° 55.4'	118°	22.5'
1963 8/09	Downey			3.2	33° 51.1'	118°	10.8'
1963 11/28	Downey			3.0	33° 49.7'	118°	09.5'
1964 2/20	Downey			3.2	33° 48.1'	118°	08'
1964 3/21	Inglewood Area			3.0	33° 56.2'	118°	24'
1965 11/12	Santa Monica-Inglewood (felt over 800 sq. mi. of SW L. A. County - most sharply in Santa Monica-Inglewood).			3.0	33° 58.8'	118°	23.5'
1966 6/13	Orange County			3.5	33° 44.8'	117°	59.5'
1966 10/02	Los Angeles (felt over SW L. A. County; felt sharply in Los Angeles)	IV	VI	3.8	34°	118.18°	
1967 5/12	South-Gate-Lynwood; felt in Pasadena			2.9	33° 55.8'	118°	13.2'
1968 1/19	Torrance			3.0	33° 56'	118°	16'

Date	Locality	Intensity (Modified Mercalli)		Magnitude	Epicenter			
		Maximum	Torrance		N. Lat.		W. Long.	
1969 5/05	Hawthorne			3.1	33°	55'	118°	11'
1969 10/27	Laguna Beach (off shore)			4.3	33°	32.7'	117°	48.4'
1969 12/02	Inglewood			3.1	33°	58'	118°	19'
1970 5/22	Seal Beach			3.0	33°	44'	118°	06'
1970 9/14	West Los Angeles area			3.0	34°	3.7'	118°	21.0'
1970 9/22	West Los Angeles area			4.2	34°	00'	118°	17'
1970 9/23	Inglewood area			3.3	33°	54'	118°	18'
1970 9/23	Inglewood area			3.7	33°	56'	118°	17'
1970 9/23	Inglewood area			3.2	33°	54'	118°	20'
1971 3/01	Playa del Rey			3.5	33°	59'	118°	25'
1971 11/26	Inglewood			3.0	33°	57'	118°	19'

Compiled principally by F. Beach Leighton and Associates with some modifications from the following sources:

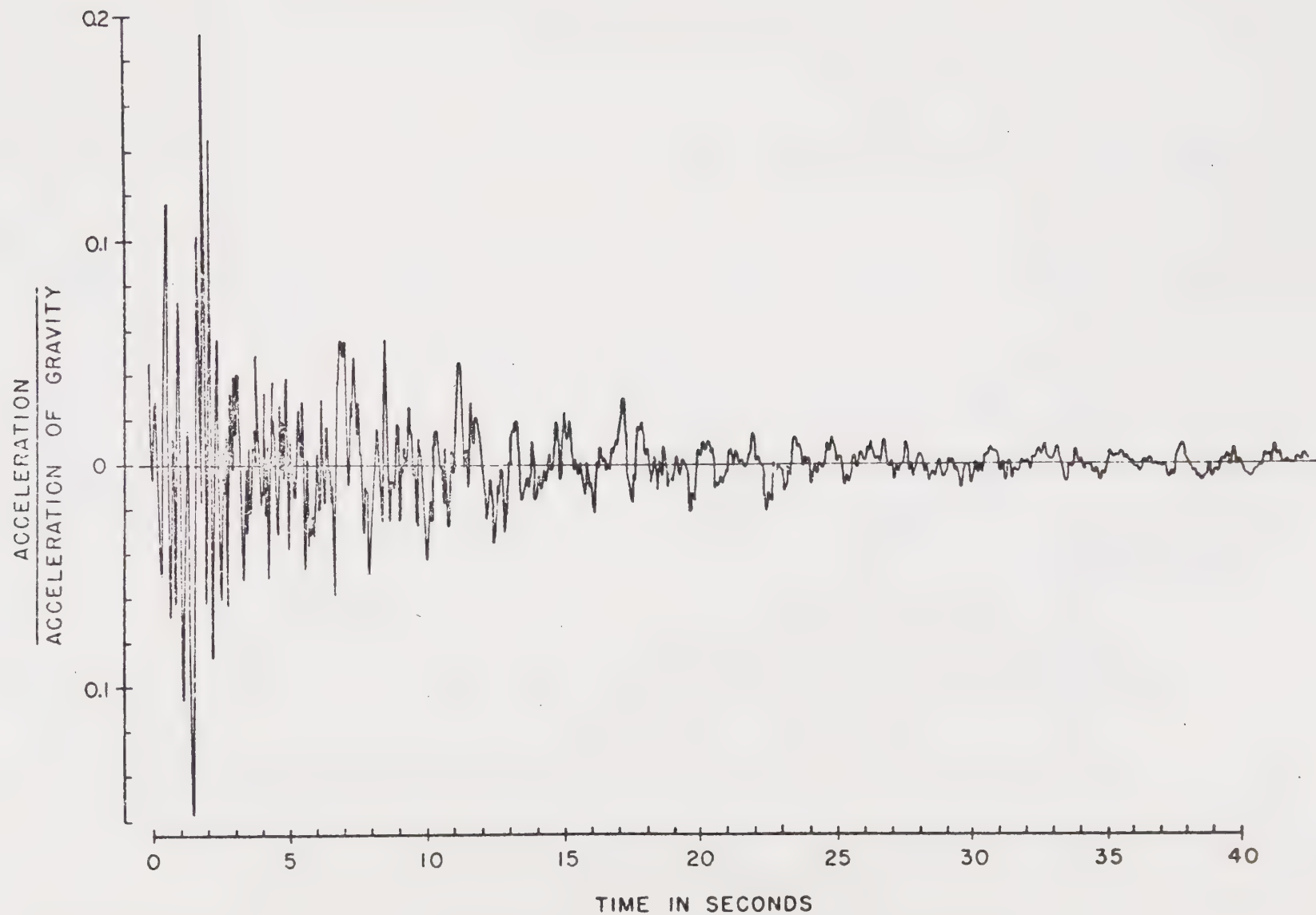
1. Calif. Dept. Water Resources, Bull. No. 116-2, 1964.
2. Seismological Notes, Bull. Seismol. Soc. America.
3. Richter, Nordquist, Taylor (1967).
4. Allen, Brune, Nordquist, Richter, Taylor (1968)
5. Caltech Computer Printout 1968-1972.

APPENDIX C
ACCELEROGRAPH RECORDS AND SPECTRA

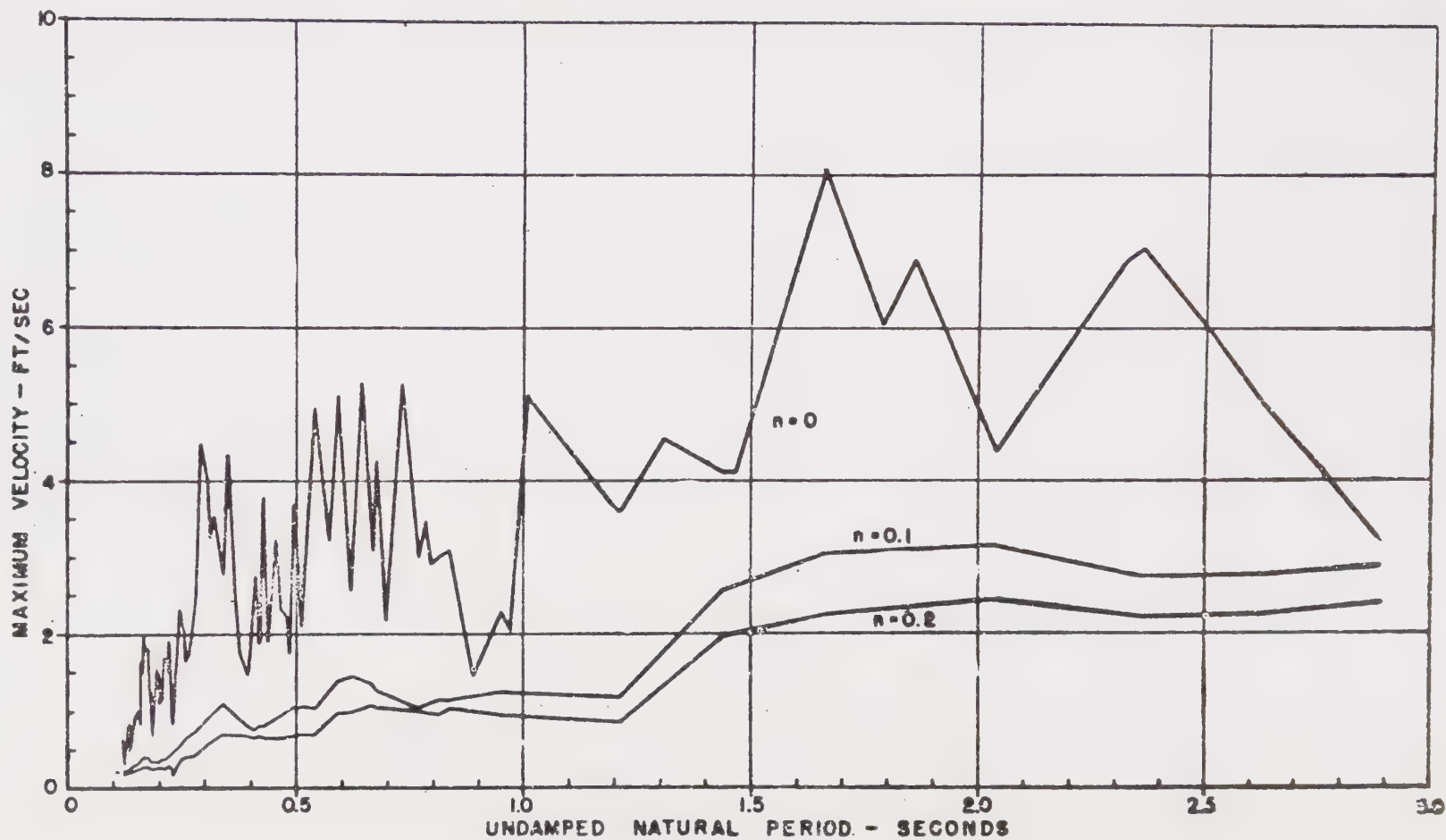
CONTENTS OF APPENDIX C

Earthquake and Date	Location of Recording	Component	Page Number		
			Accelerogram	Velocity Spectrum	Acceleration Spectrum
Long Beach (March 10, 1933)	Vernon	S82E	C-1	C-2	C-3
		N08E	C-4	C-5	C-6
	Subway Terminal	N39E	C-7	C-8	C-9
		N51W	C-7	C-8	C-10
Signal Hill (October 2, 1933)	Vernon	S82E	C-11	C-12	C-13
		N08E	C-14	C-15	C-16
	Subway Terminal	N39E	C-17	C-18	C-19
		N51W	C-17	C-18	C-20

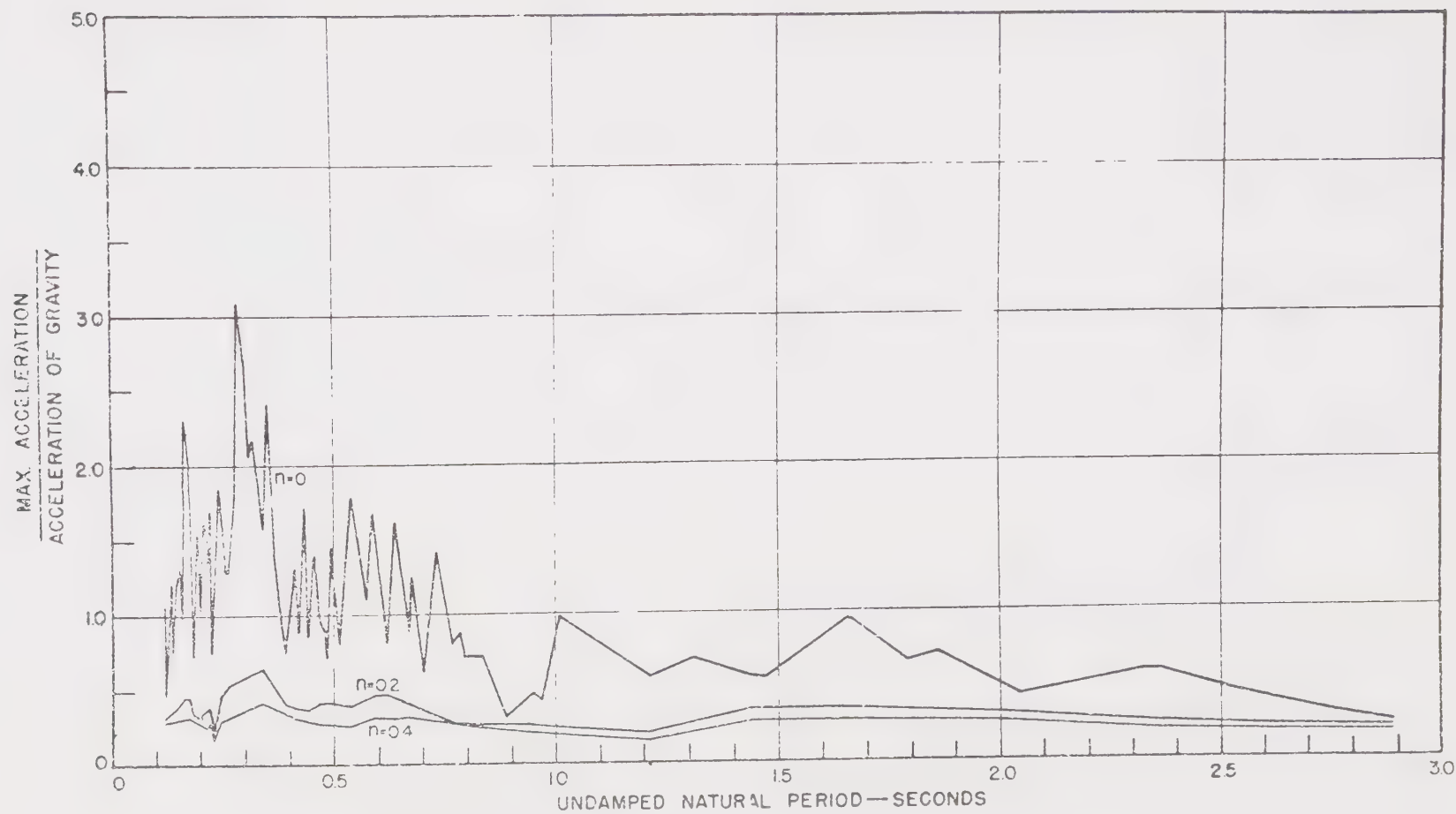
(from Alford et al, 1964)



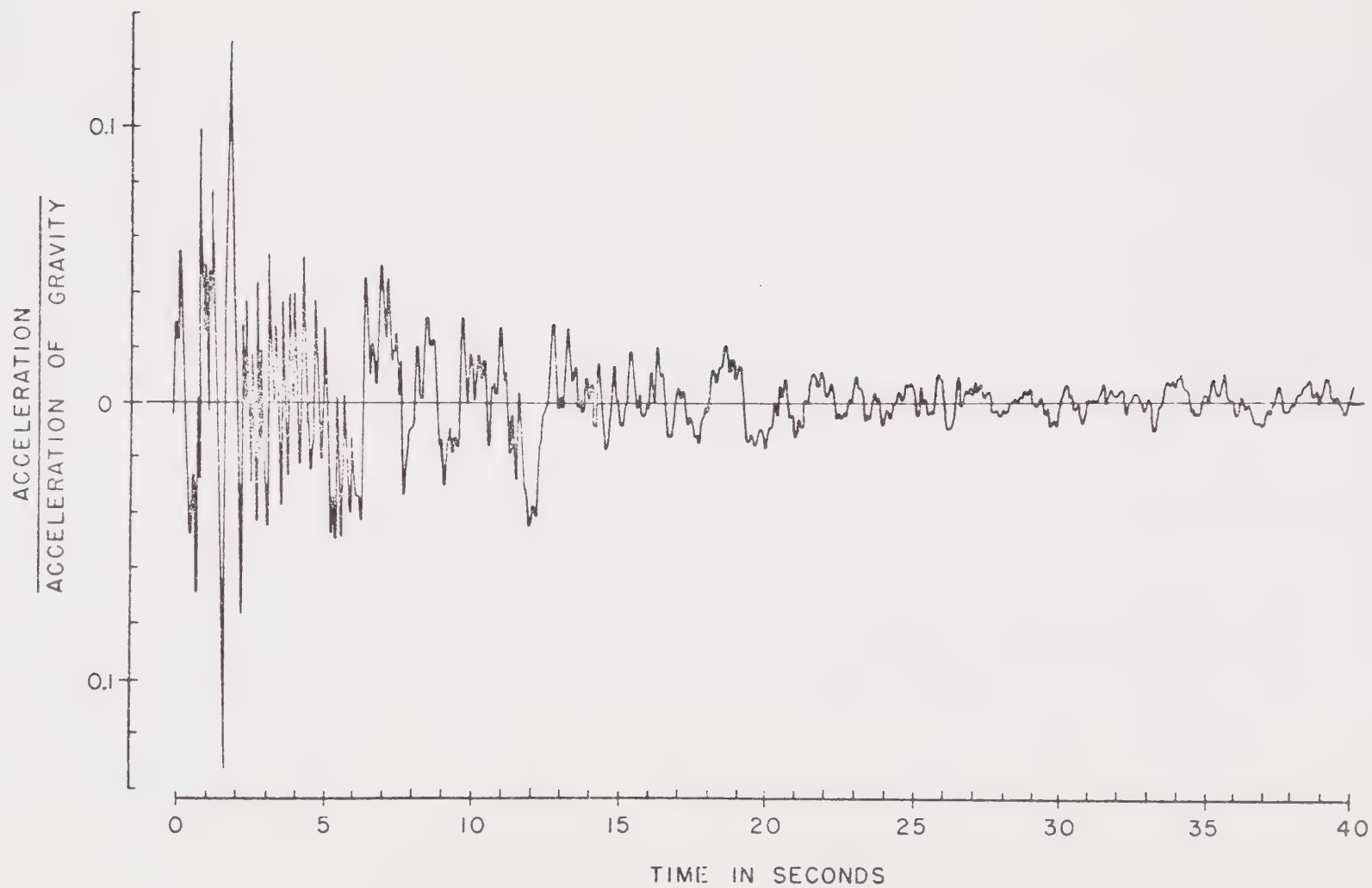
Accelerogram for Vernon, California; earthquake
of March 10, 1933. Component S 82 E.



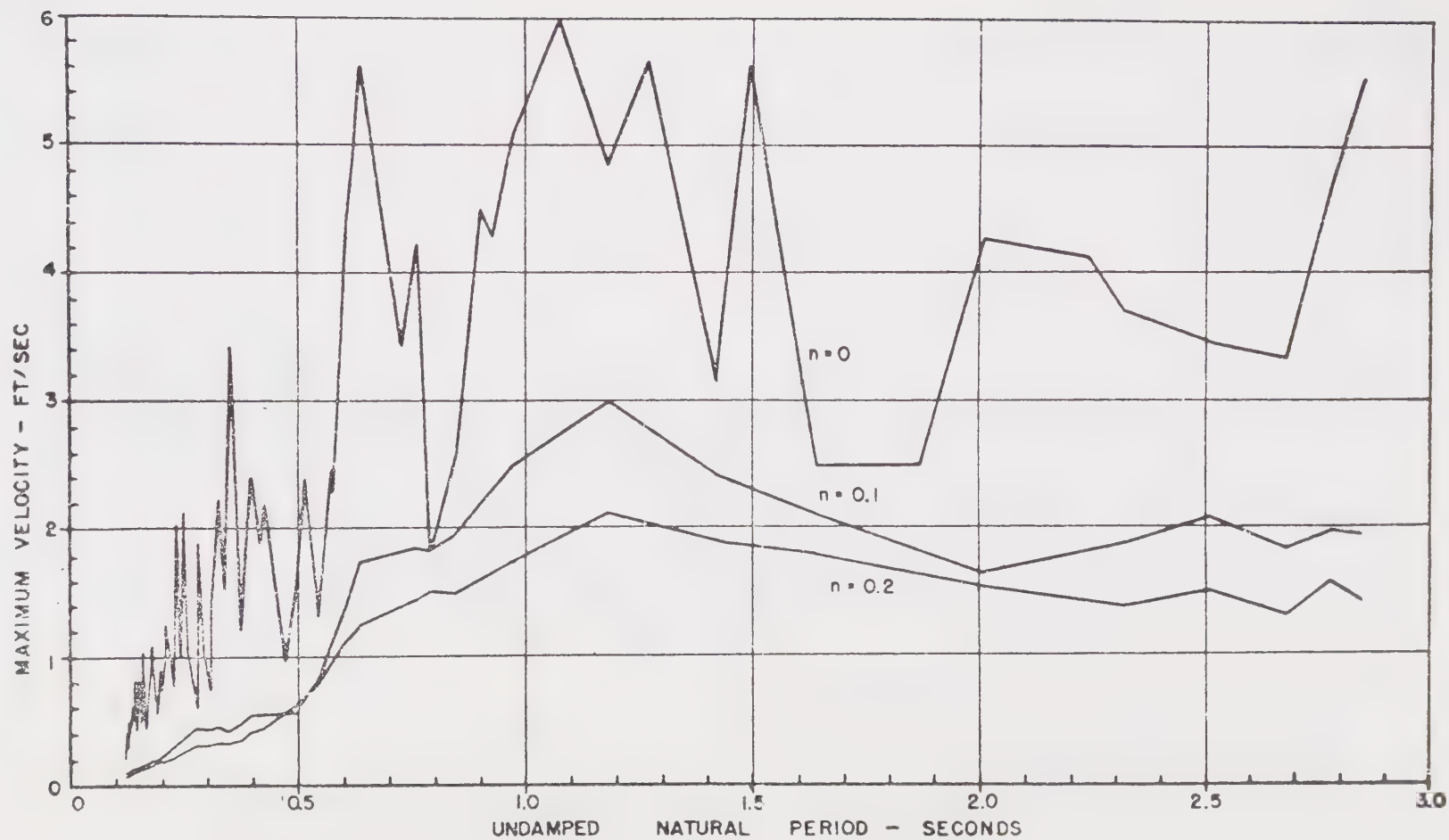
Velocity spectrum for Vernon, California;
earthquake of March 10, 1933. Component S 82 E.



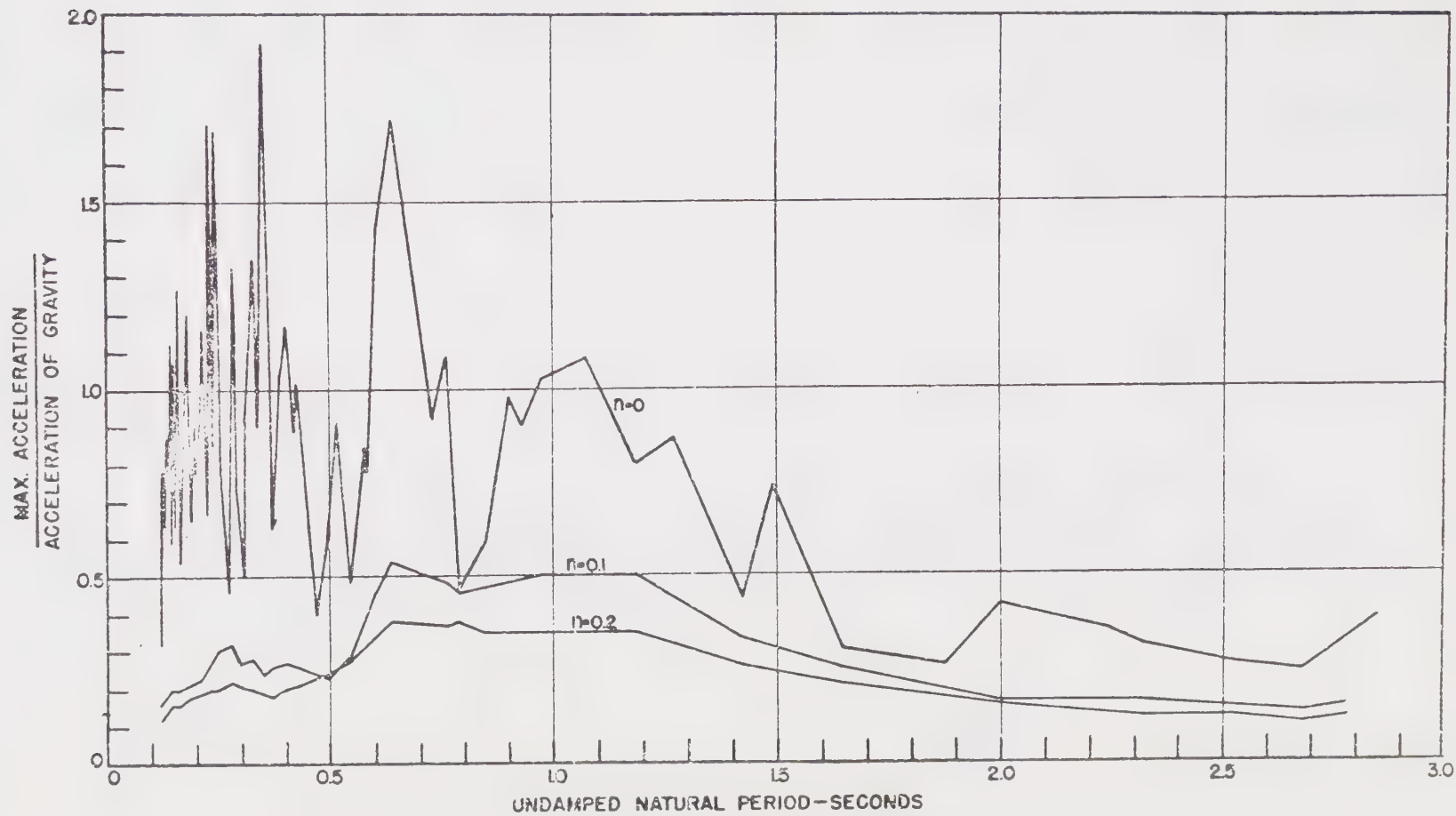
Acceleration spectrum for Vernon, California;
earthquake of March 10, 1933. Component S82E.



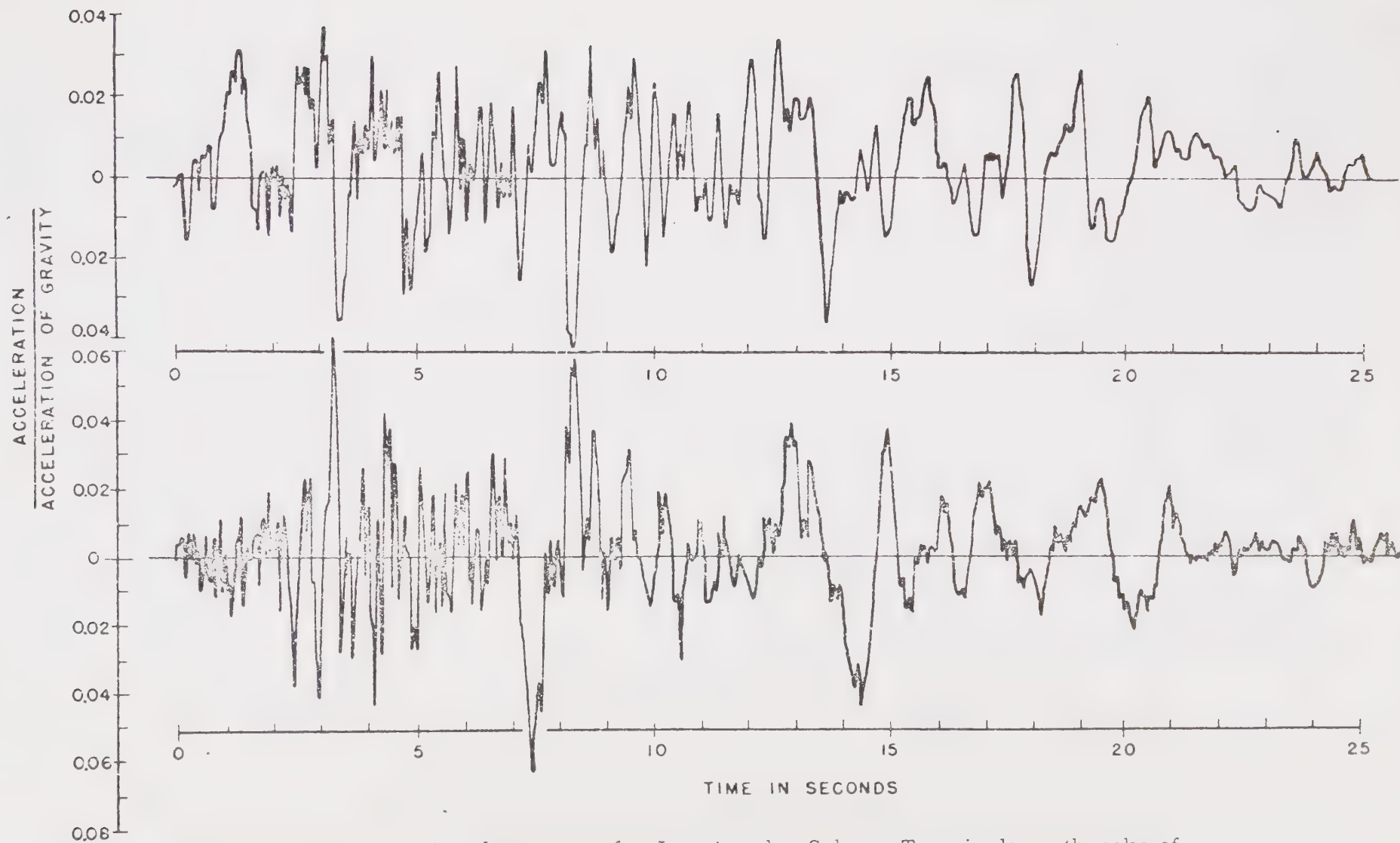
Accelerogram for Vernon, California; earthquake of
March 10, 1933. Component N 08 E.



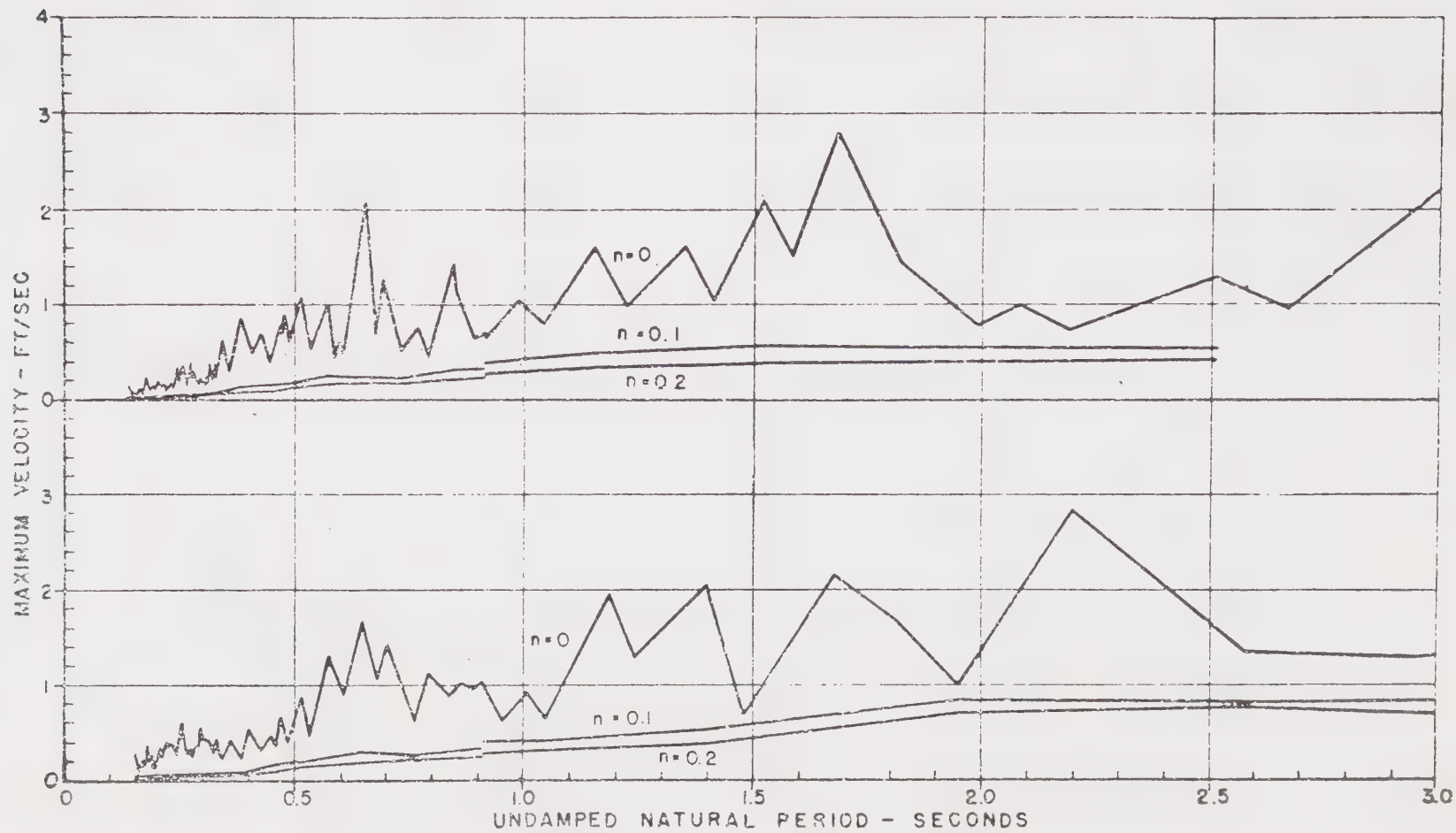
Velocity spectrum for Vernon, California;
earthquake of March 10, 1933. Component N 08 E.



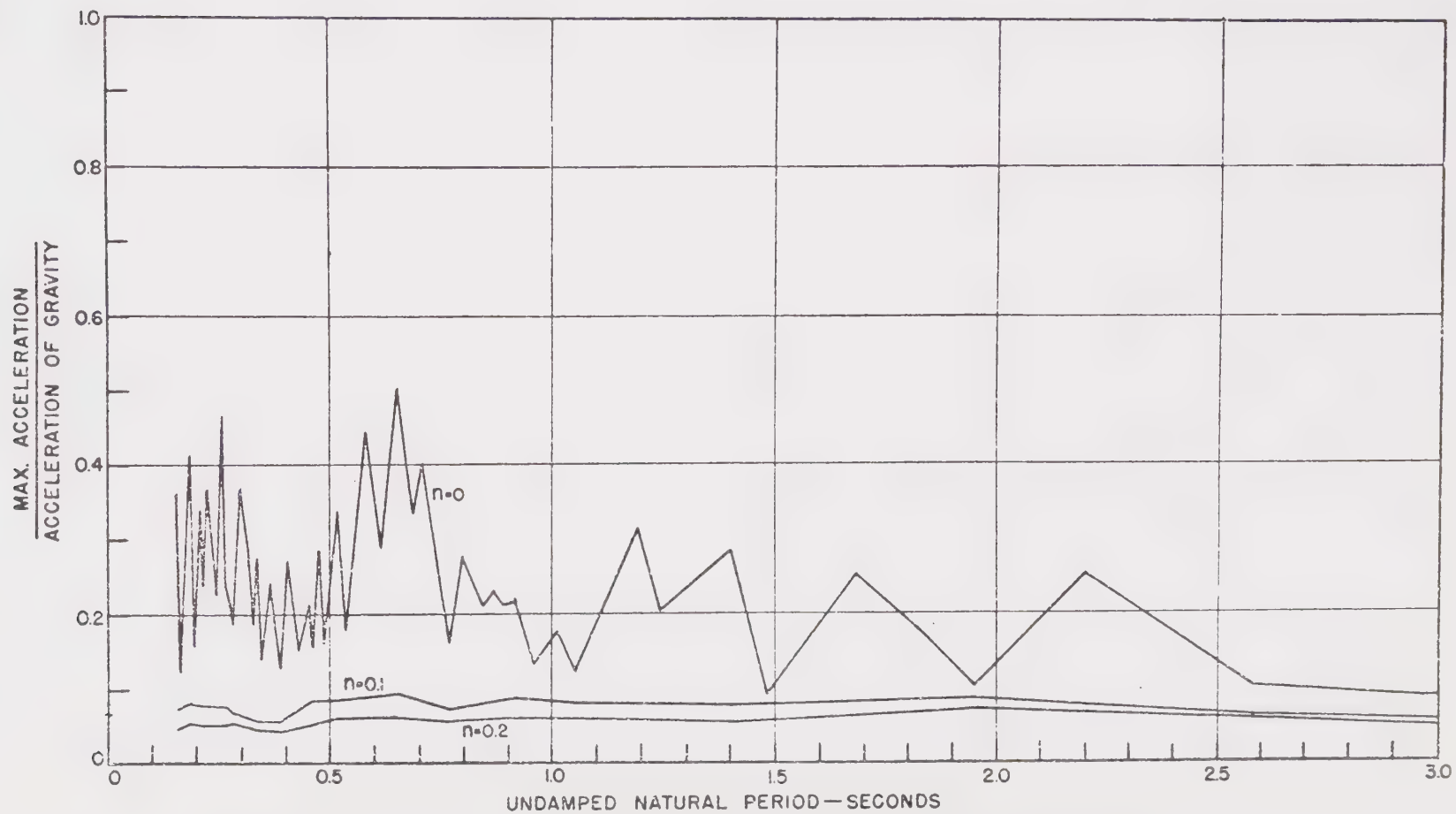
Acceleration spectrum for Vernon, California;
earthquake of March 10, 1933. Component N08E.



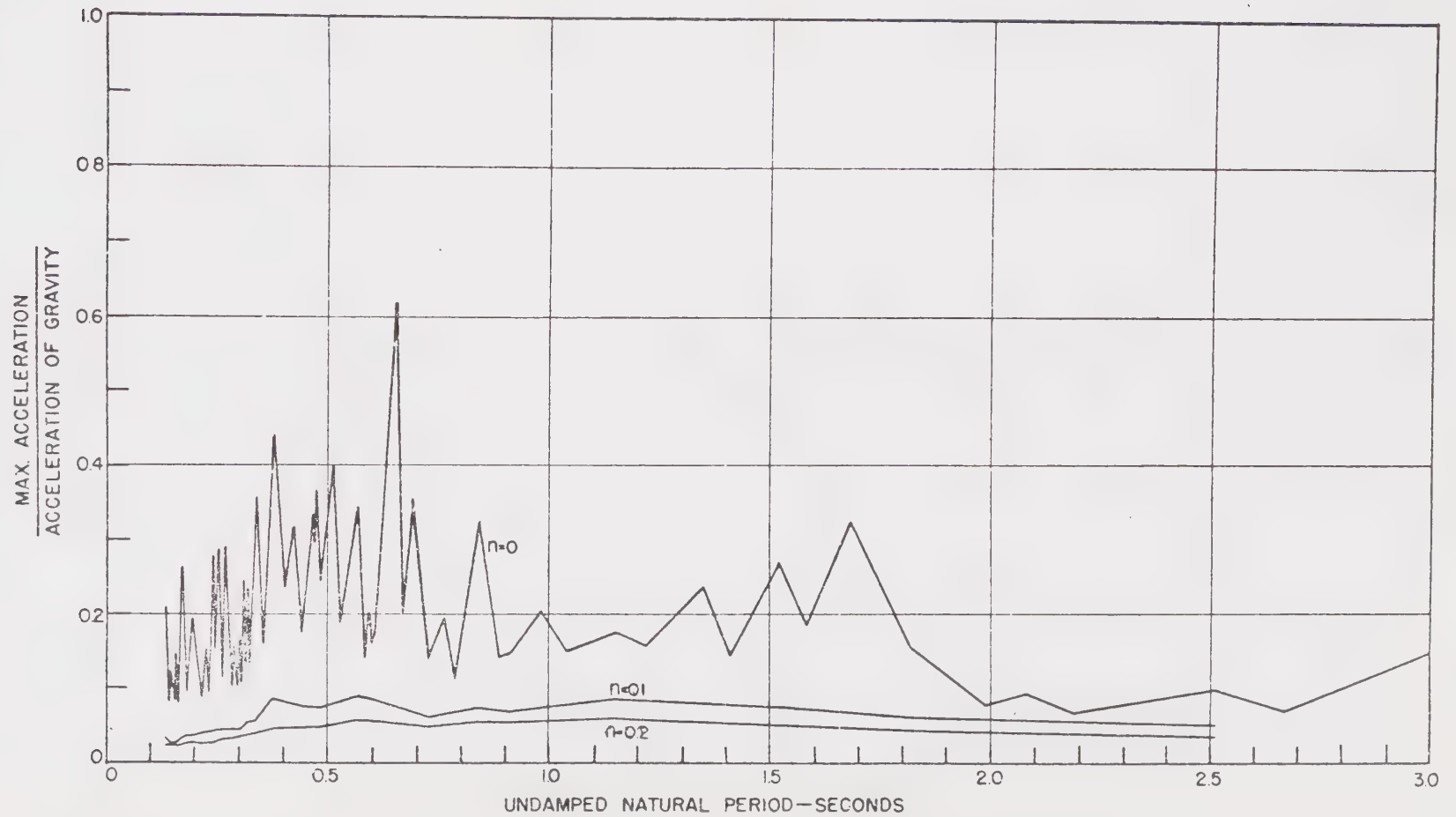
Accelerograms for Los Angeles Subway Terminal; earthquake of March 10, 1933. Components: N 39 E (lower), N 51 W (upper).



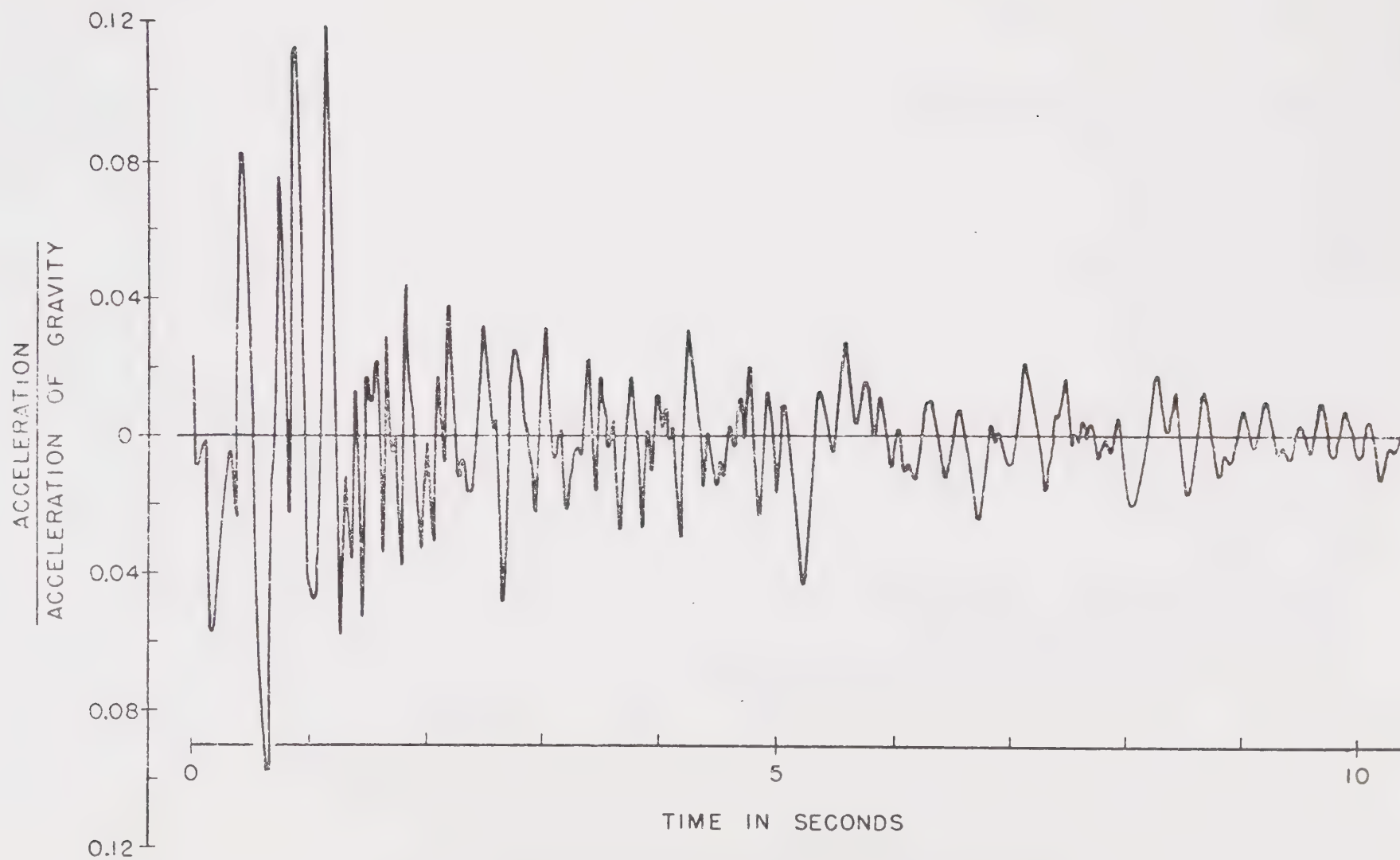
Velocity spectra for Los Angeles Subway Terminal; earthquake of March 10, 1933. Components: N 39 E (lower), N 51 W (upper).



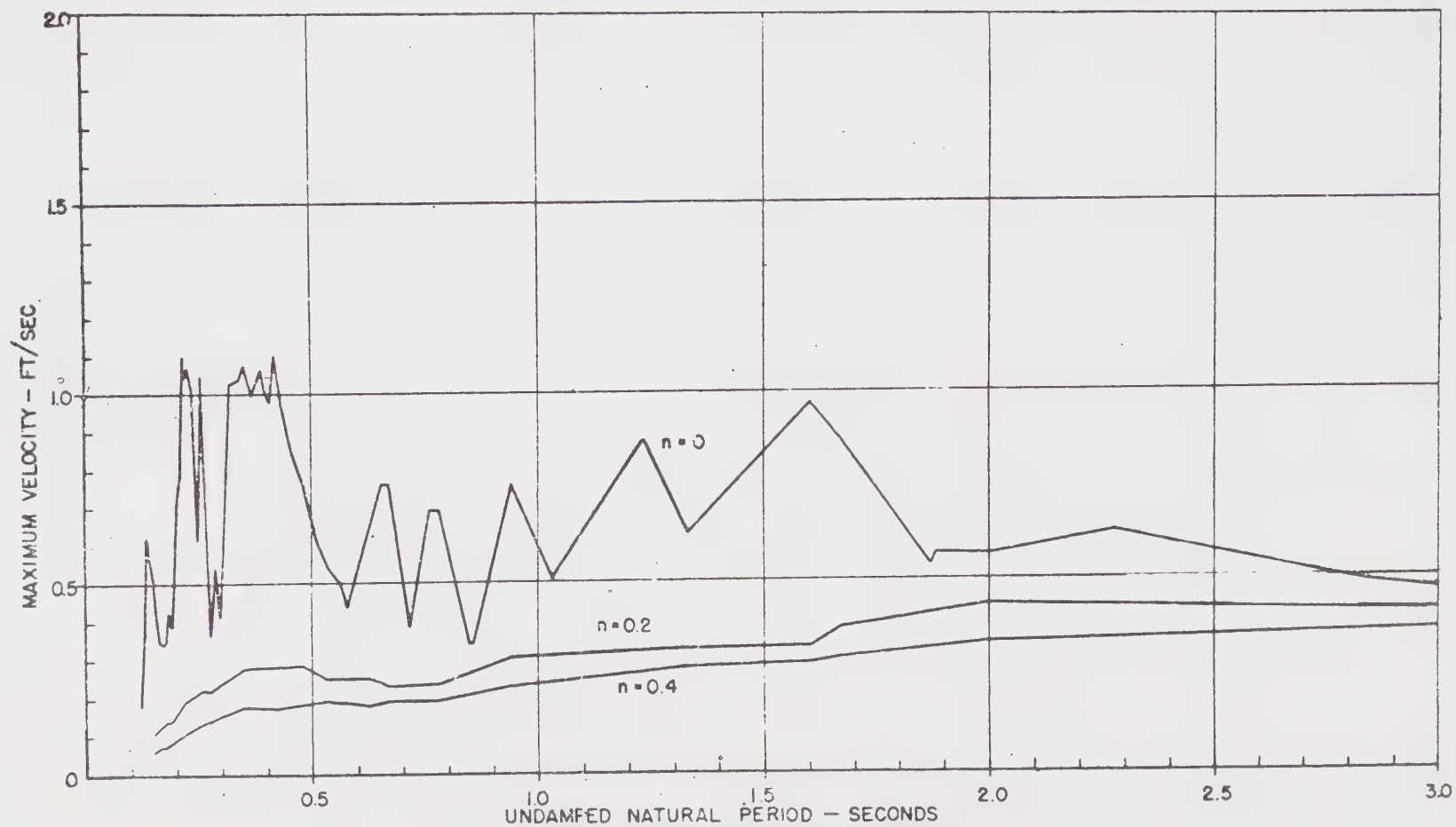
Acceleration spectrum for Los Angeles Subway Terminal;
earthquake of March 10, 1933. Component N39E.



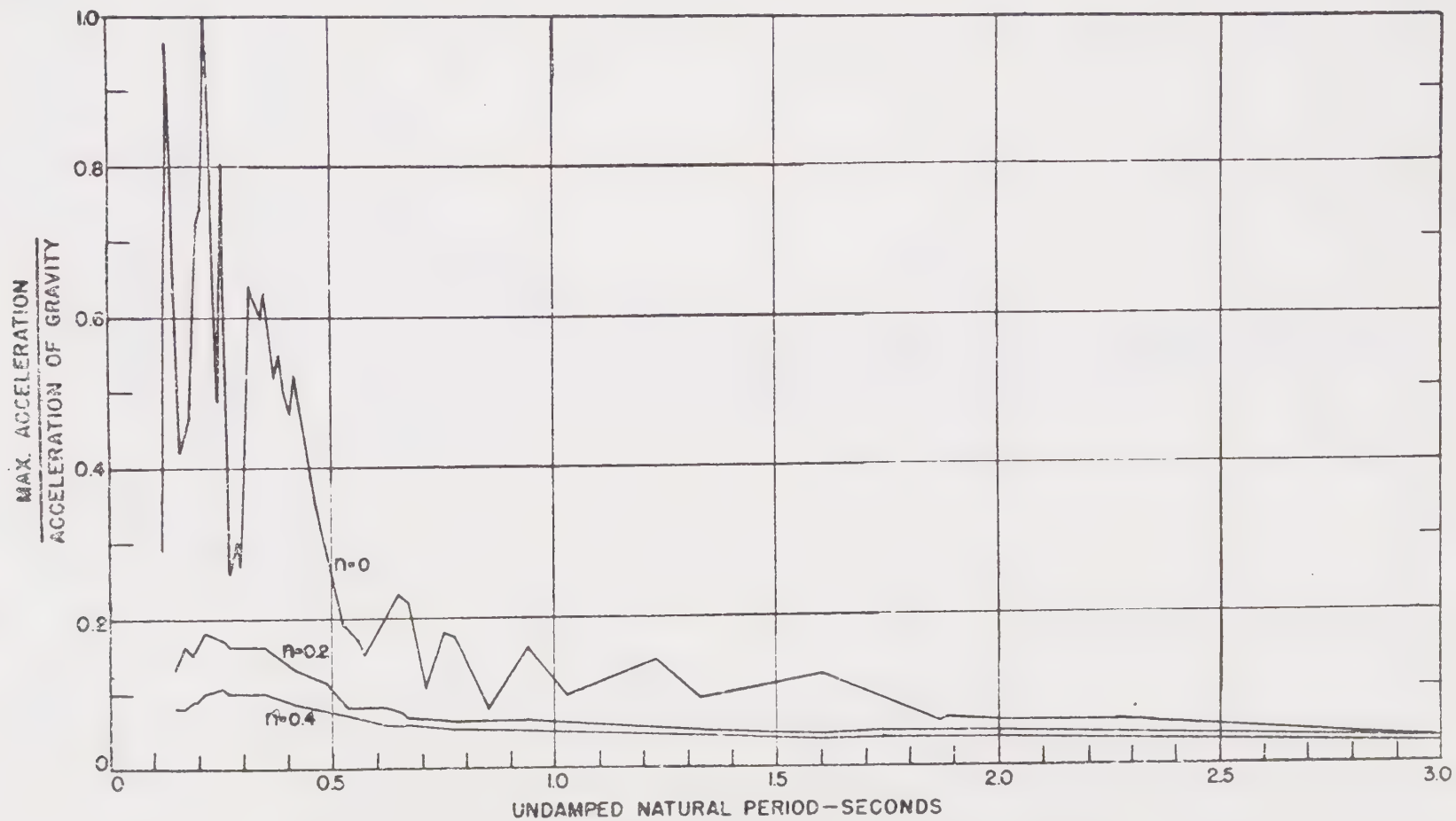
Acceleration spectrum for Los Angeles Subway Terminal;
earthquake of March 10, 1933. Component N 51 W.



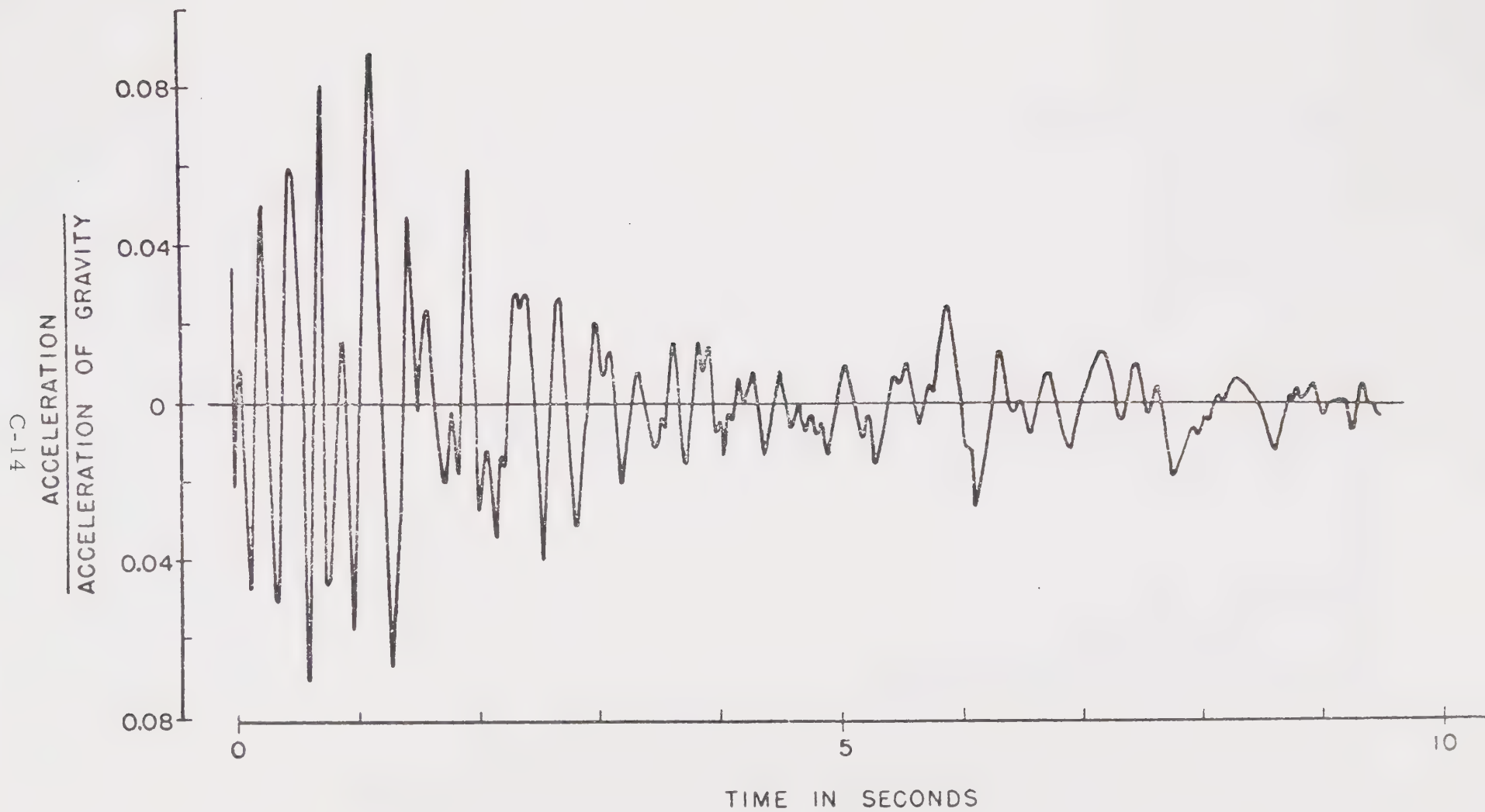
Accelerogram for Vernon, California; earthquake of October 2, 1933. Component S 82 E.



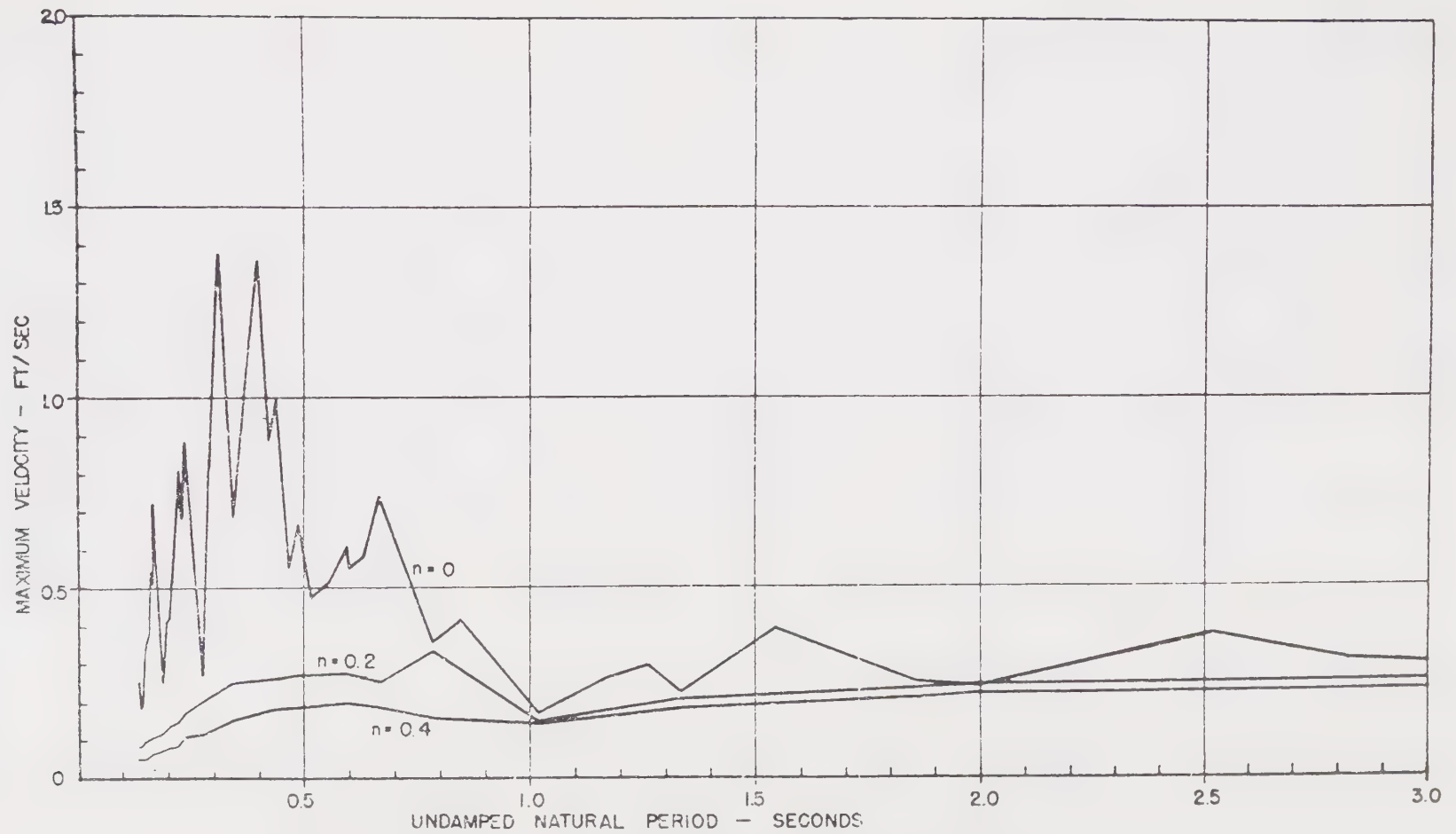
Velocity spectrum for Vernon, California;
earthquake of Oct. 2, 1933. Component S 82 E.



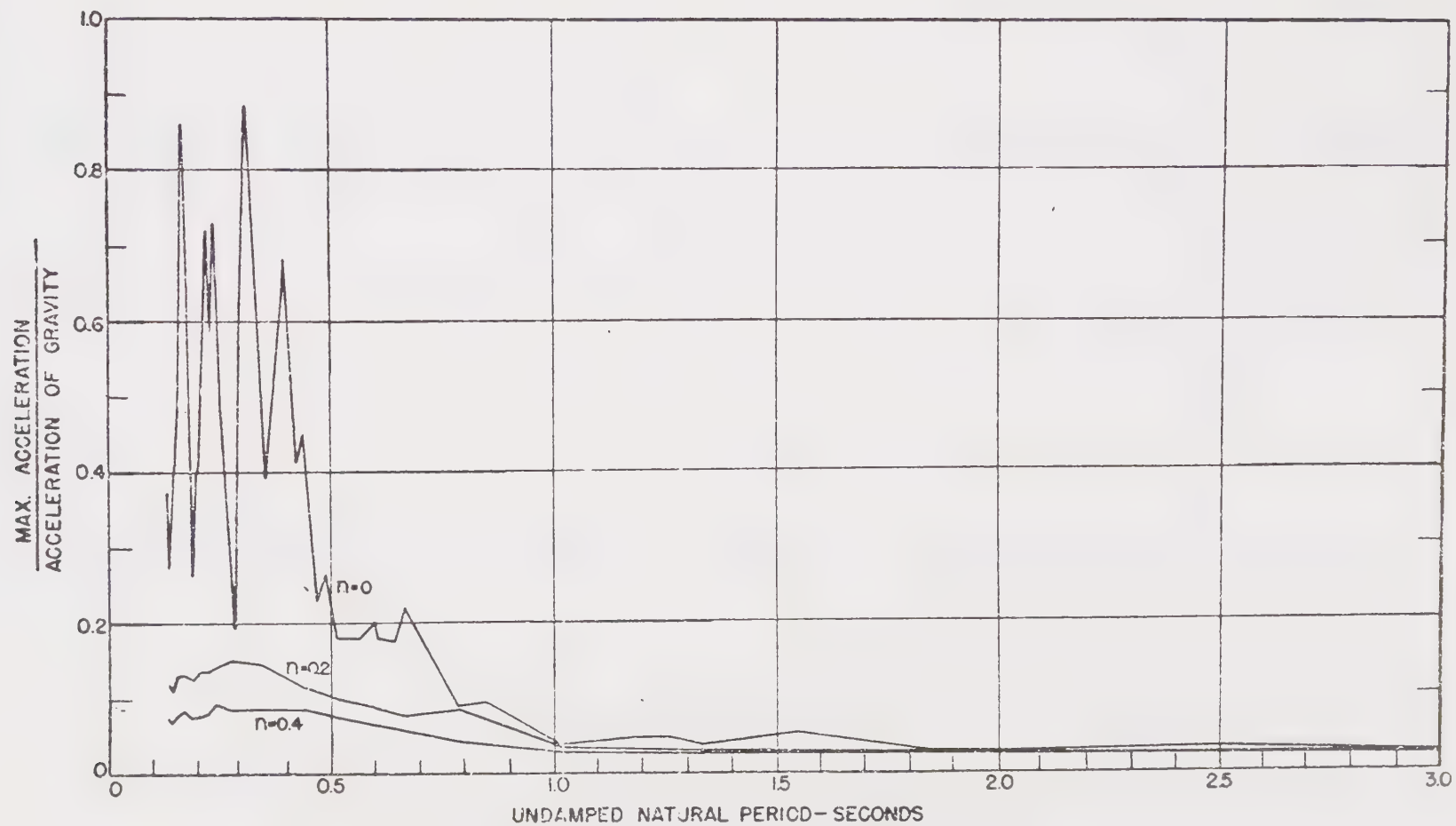
Acceleration spectrum for Vernon, California;
earthquake of Oct. 2, 1933. Component S82E.



Accelerogram for Vernon, California; earthquake of October 2, 1933. Component N 08 E.

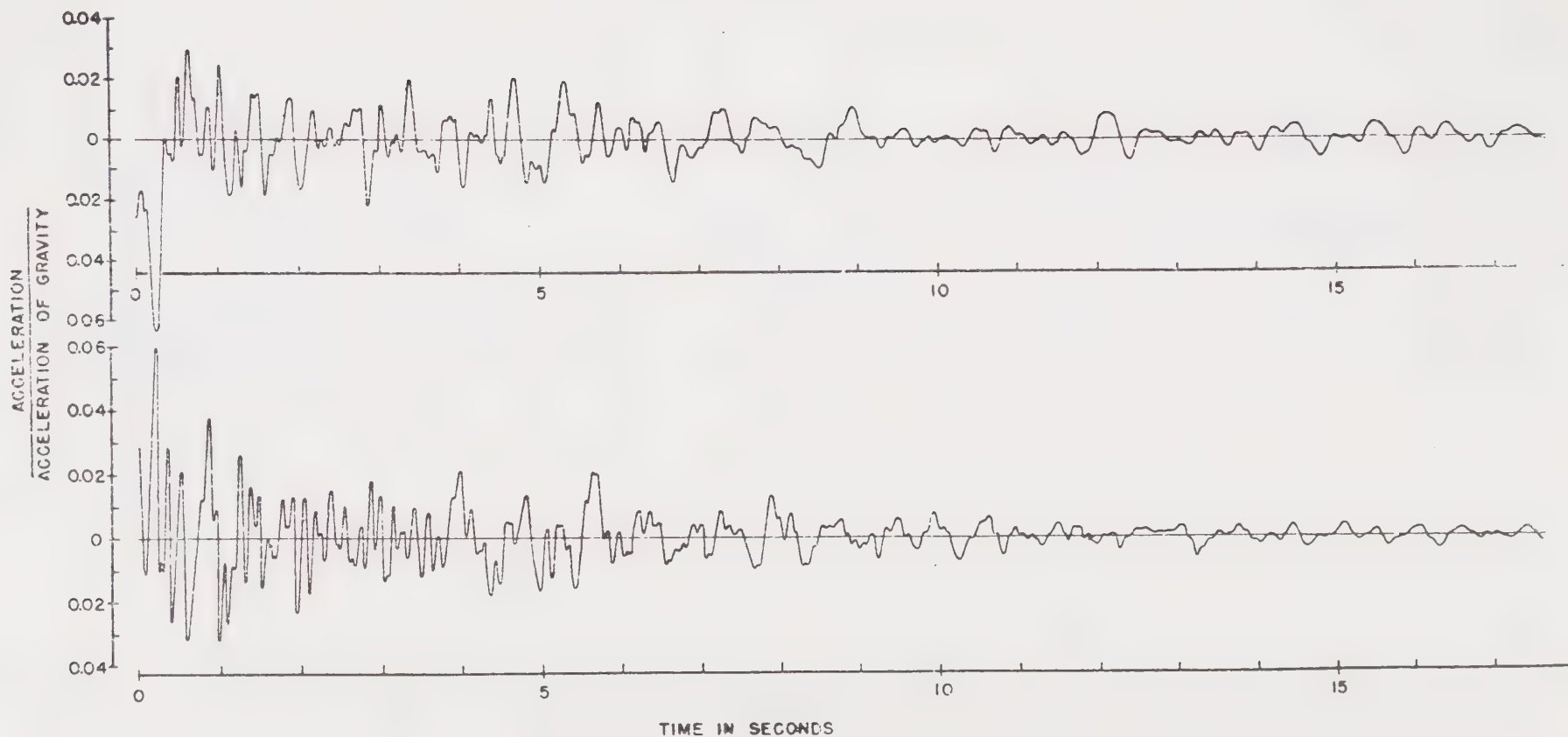


Velocity spectrum for Vernon, California;
earthquake of Oct. 2, 1933. Component N 08 E.

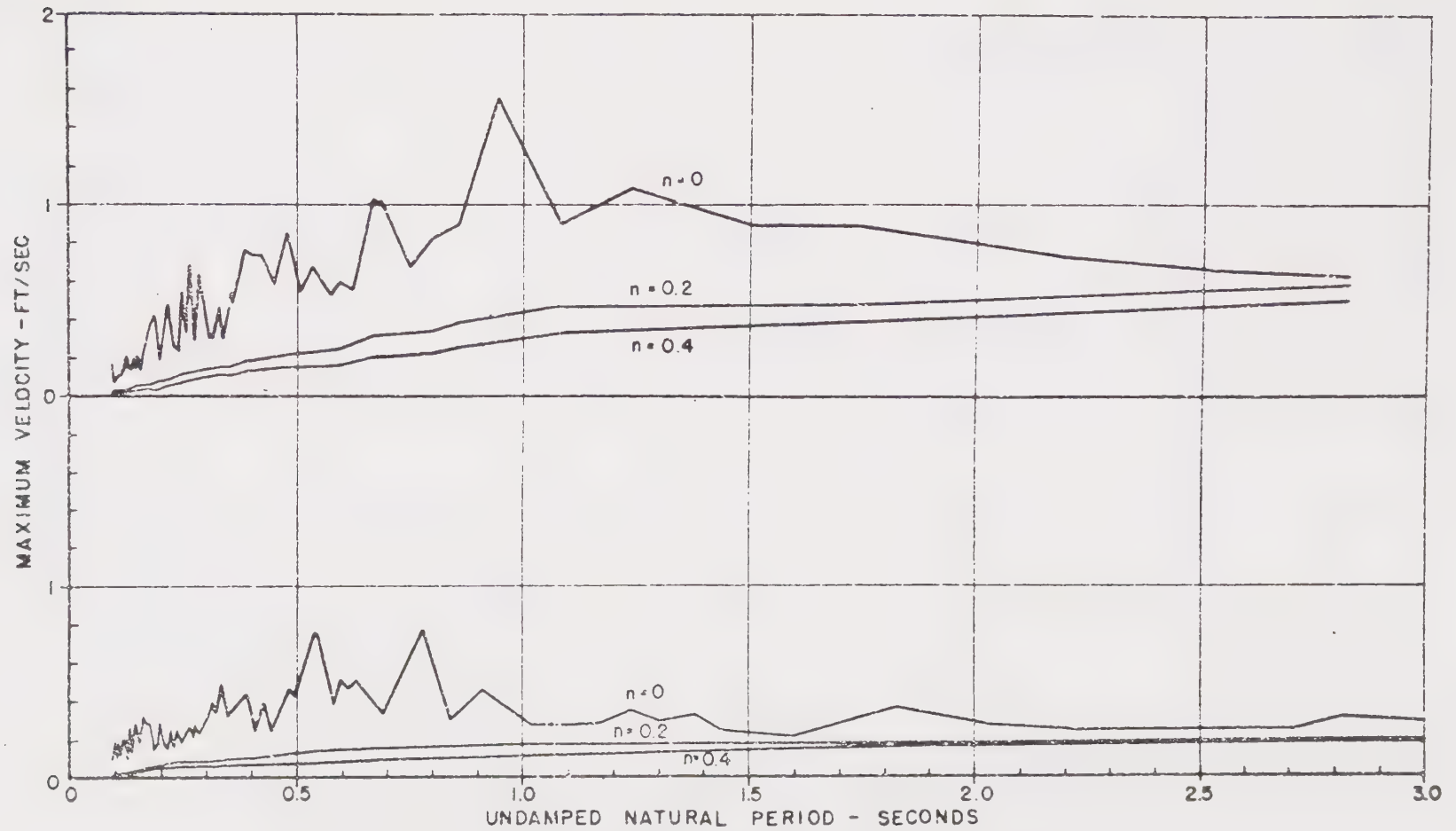


Acceleration spectrum for Vernon, California;
earthquake of Oct. 2, 1933. Component N08E.

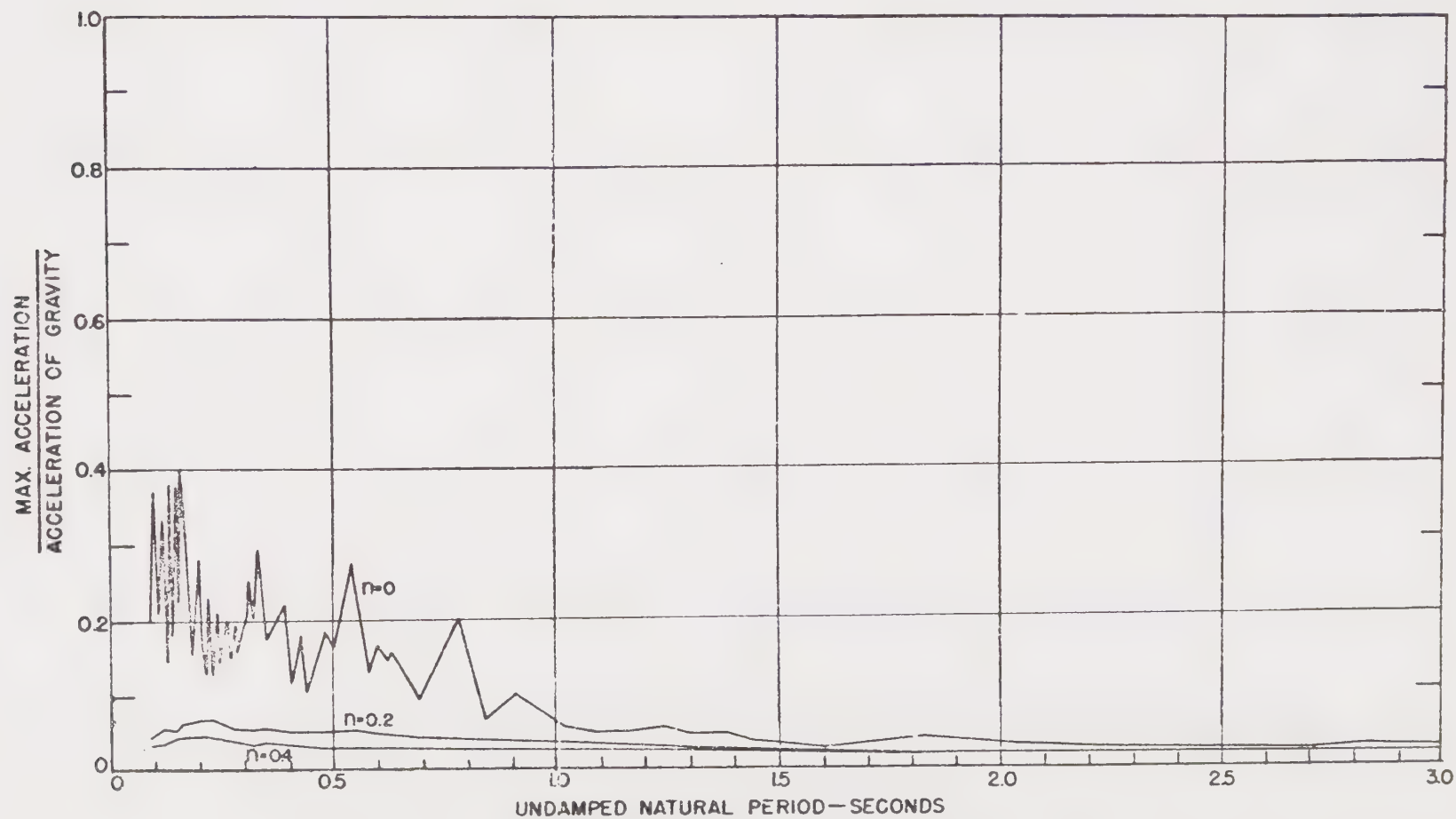
C-17



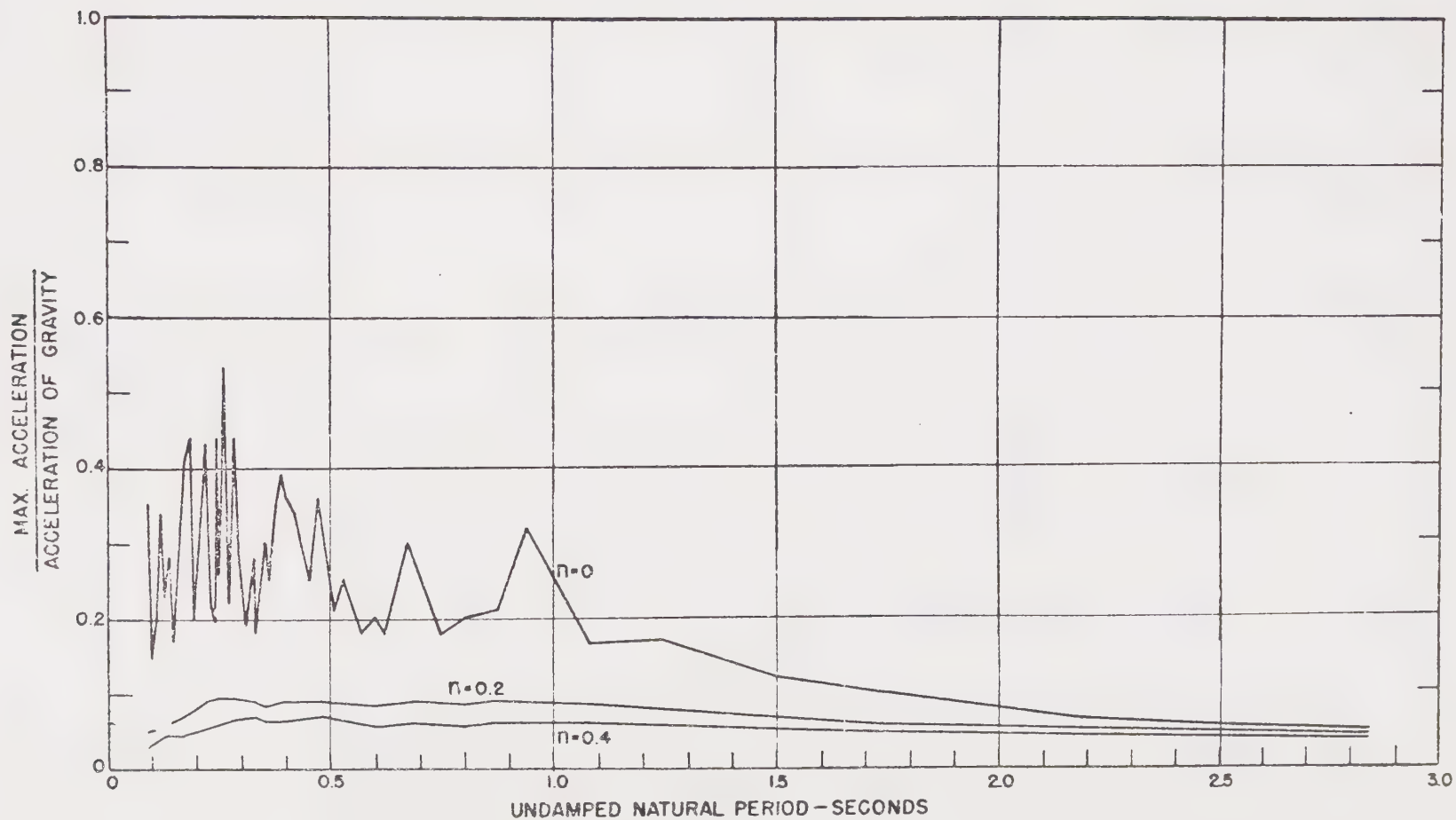
Accelerograms for Los Angeles Subway Terminal; earthquake of October 2, 1933. Components: N 39 E (lower), N 51 W (upper).



Velocity spectra for Los Angeles Subway Terminal; earthquake of Oct. 2, 1933. Components: N 39 E(lower), N 51 W (upper).



Acceleration spectrum for Los Angeles Subway Terminal;
earthquake of Oct. 2, 1933. Component N 39 E.



Acceleration spectrum for Los Angeles Subway Terminal;
earthquake of Oct. 2, 1933. Component N 51 W.

APPENDIX D
SUMMARY OF OPERATIONS
TORRANCE OIL FIELD

SUMMARY OF OPERATIONS, TORRANCE OIL FIELD

1. Oil Production

The Torrance oil field, main zone, was discovered in June 1922, and the Del Amo zone was discovered in July, 1936. The average well depth in the main zone is 3737 feet and 4971 feet in the Del Amo zone. The average gravity of oil in the main zone is 18.5 API, and that in the Del Amo zone is 24.0 API.

There are presently (1971) 476 active wells in the main zone and 121 in the Del Amo zone, with 747 main zone wells and 188 Del Amo wells abandoned. Cumulative production through 1971 has been approximately 175 million barrels with the most recent yearly rate (1971) being 1,356,216 barrels. Significant operational data for the period 1963 through 1971 are listed in Table D-1.

The field is partially unitized. The Torrance, Main Area (Tar-Ranger, Main, and Del Amo pools) was unitized September 1, 1964, the South Torrance Unit on October 1, 1968, and the Torrance Unit on July 1, 1969.

2. Water Injection

Total injected water by year is included in the data in Table D-1. These values include three separate water injection projects (Conservation Committee of California Oil Producers, 1972). The first project extended from February, 1950 to February, 1965 and involved the injection of a total of 4,709,000 barrels. The maximum injection rate was 1620 barrels/day in May, 1960. The second project extended from October, 1967 to March, 1969, with a total of approximately

TABLE D-1
SIGNIFICANT OPERATIONAL DATA, TORRANCE OIL FIELD, 1963-1971

	1971	1970	1969	1968	1967	1966	1965	1964	1963
<u>Wells:</u>									
Shut-in	186	159	133	121	109	111	91	81	114
Producing	411	450	477	520	566	583	614	636	656
Total	597	609	610	641	675	694	705	717	770
<u>Production:</u>									
Barrels/year	1,356,216	1,185,418	1,270,696	1,518,210	1,585,277	1,620,929	1,677,845	1,830,274	1,956,758
Barrels/day	3,716	3,248	3,481	4,148	4,343	4,441	4,596	5,001	5,361
Cumulative	174,928,967	173,572,751	172,387,333	171,116,637	169,598,427	168,013,150	166,392,221	164,714,376	162,884,102
Gas (MCF/year)	813,464	843,800	994,965	1,141,272	1,248,883	1,269,297	1,246,045	1,319,065	1,368,896
GOR	491	609	813	591	744	825	782	700	706
<u>Water:</u>									
Produced (B/year)	3,387,381	2,051,403	2,429,802	3,331,559	3,405,708	3,552,575	3,619,197	3,911,478	3,856,000
Injected (B/year)	9,354,665	522,858	232,109	1,077,524	98,271	—	2,045	—	277,225
Compiled from: Annual reviews of California oil and gas production, Conservation Committee of California Oil Producers for the years 1963 through 1971, published 1964-1972.									

1,408,000 barrels injected. The maximum injection rate was 3361 barrels/day in April 1968. These two projects were a relatively modest undertaking. The total injected water over the 19-year period was less than 20% of the oil, and only about 6% of the total fluid withdrawn during the injection period. The maximum injection rate did not exceed even the daily oil production rate, much less the rate of total fluid withdrawal.

The most recent project was begun in May, 1970 with the total injected water to the end of 1971 being 11,286,000 barrels. The average rate during 1971 was 30,344 barrels/day with the maximum rate of 37,243 occurring in September. The operation is a pattern flood type with 27 active and 2 suspended injection wells in 1971. The 1971 rates exceed fluid withdrawal by approximately 2:1 (see Table D-1), and have apparently increased production by about 200,000 barrels/year.

APPENDIX E
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REPORTS FROM FILES OF THE CITY OF TORRANCE

Northeast Flank of Palos Verdes Hills

Tract 30152:

1. Geotechnical Consult. (12-28-64)
2. C.A. Yelverton (5-24-65)
3. Western Laboratories (9-22-65)

Tract 30301:

1. Geotechnical Consultants (12-29-64)
2. Geotechnical Consultants (5-7-70)

Tract 26507:

1. Western Laboratories (10-13-71)
2. Emil Di Matteo (10-11-71)
3. Emil Di Matteo (2-5-72)
4. Western Laboratories (2-22-72)
5. Lindvall, Richter & Assoc. (4-10-72)
6. Emil Di Mateo (4-21-72)
7. Emit Di Matteo (5-8-72)
8. Lindvall, Richter & Assoc. (5-18-72)
9. Emil Di Matteo (9-5-72)

Tract 9765:

1. Glenn Brown & Assoc. (12-2-69)

Beach Area

Tract 10303:

1. Converse, Davis & Assoc. (2-1-72)

The Esplanade:

1. R. T. Frankian & Assoc. (4-16-71)

Tract 18379:

1. Converse Foundation Engineering Co. (8-29-60)

Central Area

Golden West Towers:

1. R. T. Frankian & Assoc. (9-15-71)
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